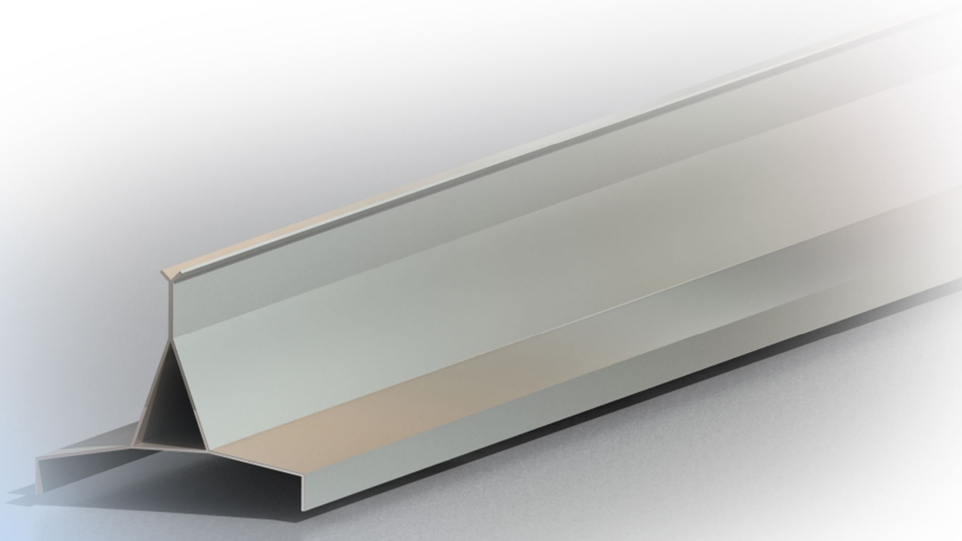
EPS

Spring 2011



Group1

Nano-RUF

Team members:
Jorge Azcoitia
Kaat Delcoucq
Tom Giddings
Josep Manresa
Christoph Regler

Supervisors:
Palle R. Jensen
David Ashworth

Abstract

This report is a description of the work completed for the Nano-RUF concept vehicle. The report includes information on the background of the RUF system, research into existing personal mobility concepts, components and a proposal of materials. Explanations are given on how the group reached certain decisions and the systematic approaches that were used to achieve them. The report describes the design of the Nano-RUF and the reasons for choosing the solutions adopted for each feature. A final concept is presented and technical data is given. It follows an in depth business proposal that could help develop the Nano-RUF on a larger scale. Focussing on obtaining investor proposals. The report gives detailed estimations on the vehicles performance and structural characteristics. A description is given about the construction of a 3D animation that displays the Nano-RUF in its environment.

Contents

List of Figures

List of Tables

1. Introduction

It is clear that personal mobility has become a necessity in society. The use of motorized vehicles has increased throughout the 20^{th} and the 21^{st} century until the point that nobody can imagine the world without cars, motorbikes, vans or trucks.

But in the last few years several factors have made obvious that an evolution of the current system of transportation is an absolute necessity. The massive use of engines fuelled with oil derivate products is the cause of air pollution and global warming. It is also decreasing the oil resources of the planet and consequently increasing their price.

For years, new technologies to fuel vehicles for transportation have been developed, especially by means of electricity and hydrogen. But converting current oversized vehicles fuelled with fossil fuels into electric fuelled vehicles is not enough to make the system sustainable. This is because although the efficiency of the vehicles is being increased, the energy required for the generation of electricity or hydrogen is still too high and unsustainable (mainly it is still dependant on fossil fuels).

So the efforts should focus on designing vehicles and transportation systems which require less energy and finding new and efficient sources of energy. It is also necessary to change the traditional way of thinking; owning a big and powerful car as a demonstration of a social status. However, the new automobiles should be designed to have high consumer appeal; they have to be fun, fashionable and affordable. This is crucial because only through the acceptance of the consumers will the evolution of transportation to a sustainable model be possible.

As a way to improve the efficiency in transportation it appears RUF or “Rapid Urban Flexible” offers a new concept of transportation essentially based in vehicles which are able to drive in two modes. In villages or city centres these electric powered vehicles can drive independently like any other vehicle. In main roads they are able to couple with other similar vehicles and drive on a monorail creating trains in order to reduce the air friction.

The Nano-RUF is the smallest member of the RUF family. It is a small vehicle for urban transportation essentially focused on being able to carry just one person for their short urban journeys. Bearing in mind that dimensions and energy consumption are closely related in a vehicle and the benefits of the RUF system, the Nano-RUF concept promises to be a highly efficient and flexible way to move all around the city.

2. Aim

The aim of this project is to dimension and describe a compact personal mobility vehicle for urban use that is adaptable for the RUF rail system.

The feasibility of the concept must be proven by means of defining its potential users and studying its main technical aspects. The design must fit the city environment, so a compact lightweight chassis that is cheap to produce is essential. The vehicle must be safe, economical and environmentally friendly. The overall product must be aesthetically pleasing and appeal to the target market. Given the complexity of the project, it will be focused on the achievement of an overall layout, a dimensional estimation and an overall performance based on physics and mathematics. Giving way to future projects focusing on specific fields of the vehicle, such as suspension, materials, batteries, motor, chassis, ergonomics, adaptation to legislation, etc.

3. Resources

In this chapter the most important resources of the group are listed. The group's supervisors – David Ashworth and Palle R Jensen – and the establishments and facilities at IHK were important resources. The team members are the most important resources, therefore their background is shown briefly. Each member has special skills and knowledge areas. The task was to try to use everyone's strengths and combine them to form a successful project team.

Kaat Delcoucq:

Studies: Product Design

Other resources: design shapes, sketching, ergonomics, CAD-modelling, animation

Nationality: Belgium

Home university: Howest Department PIH

Tom Giddings:

Studies: Product Design

Other resources: language, product design (basic engineering knowledge, ergonomics, anthropometrics, CAD, sketching)

Nationality: English

Home university: Nottingham Trent

Christoph Regler:

Studies: Industrial Engineering and Management

Other resources: business and economic background, research, evaluating alternatives, materials

Nationality: German

Home university: University of Erlangen-Nuremberg

Jorge Azcoitia Moreno:

Studies: Industrial Engineering

Other resources: car dynamics background, creative thinking, and research

Nationality: Spanish

Home university: Universidad European de Madrid

Josep Manresa Nadal:

Studies: Electrical Engineering

Other resources: background in electrics, car dynamics background, creative thinking and research.

Nationality: Spanish

Home university: Universidad Politécnica de Catalunya

The software programmes used for the projects are listed below. This includes a brief description what the programme is about, followed by the application of the group.

- 3D Studio MAX: 3D modelling, animation, and rendering software – used for creating Nano-RUF images and the driving process animation.
- Autodesk Alias: Design software, mainly conceptual design - used for creating the basic Nano-RUF shape.
- AutoCAD: CAD software application for 2D and 3D design and drafting – used for engineering drawings.
- Autodesk Inventor 3D: Mechanical design and 3D CAD software - used for creating the Nano-RUF shape.
- CES EduPack: Materials and Processes Database – used for selection and description of materials.
- MATLAB: high-level numerical computing environment and technical programming language – used for mathematic simulations and calculations.
- MS Project: Project Management software program – used for structuring the group work.
- MS Visio: Diagramming tool and program – used for easy creation of images and diagrams.
- Photoshop: Digital Imaging software – used for engineering drawings and Figures.

4. RUF System

4.1. Inventor

The RUF system was invented by electronic engineer Palle R. Jensen and has been under development since 1988.

4.2. The Company

Figure 4.1: Logo RUF International (Source: http://www.ruf.dk/files/index.htm)

RUF International investigates all kinds of transportation systems. During the years they have defined a new kind of system, the dual mode system. It is completely new and it is based upon electric vehicles.

There were already four patents that have been granted since 1990. Only one of them has been followed up. Patent no. 4 was granted in year 2003: US Pat. No. 6,523,480. (Appendix 2)

RUF International is owned by Palle R. Jensen.

4.3. Dual Mode System

Dual mode means that the vehicle can drive on two systems: The vehicle can drive on the ordinary streets and it can be adapted to a special monorail.

On the road the vehicles are manually controlled. On the guide way system all vehicles drive automatically. "The dual mode system combines the flexibility of a car with the environmental advantages of a train" [Jensen 2008].

Figure 4.2: RUF on the monorail (Source: http://www.ruf.dk/files/index.htm)

4.4. The Monorail

The monorail has a triangular shape that is very simple and utilizes minimum space. The complete monorail system consists of several junctions that are connected within a certain area. Every 5 km there will be a junction where it is possible to enter the monorail. It is used at high speed and long distance. The stations are offline. It is always possible to enter a junction without stopping. Entering monorail speed is about 30km/h. The highest speed that can be reached is 150km/h.

Figure 4.3: Monorail

(Source: http://www.ruf.dk/files/index.htm)

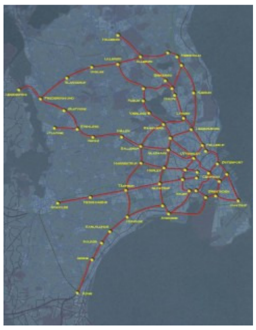


Figure 4.4: Network of guide way

(Source: http://www.ruf.dk/files/index.htm)

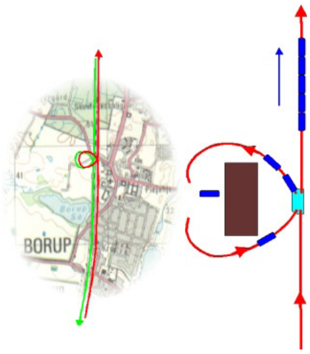


Figure 4.5: The switch

(Source: http://www.ruf.dk/files/index.htm)

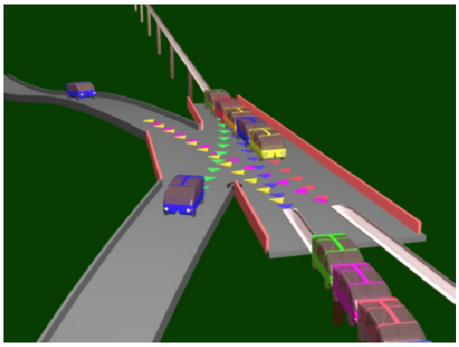


Figure 4.6: The switch

(Source: http://www.ruf.dk/files/index.htm)

The monorail is also a source of energy. If the vehicle is driven on the monorail the battery will be charged. If the car leaves the monorail the charged battery can be used to drive on the road and drive to the final destination. That is the reason why a large battery is not needed in the car. The distance the car can reach with the battery depends to the vehicle.

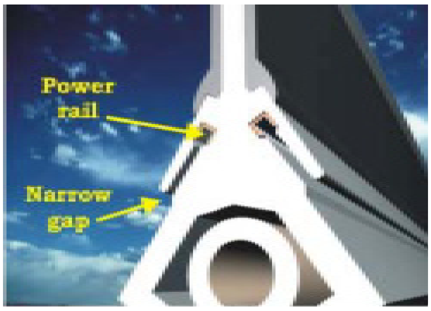


Figure 4.7: Monorail charging system (Source: http://www.ruf.dk/files/index.htm)

The dimensions of the monorail can be found in Appendix 2.

4.5. Driving System

The driving system of the RUF consists of two wheel motors. To drive on the monorail the wheel motors will be pressed against the top of the triangular monorail. This can be seen on Figure 4.8. The motors are used for driving on the monorail and for road driving.

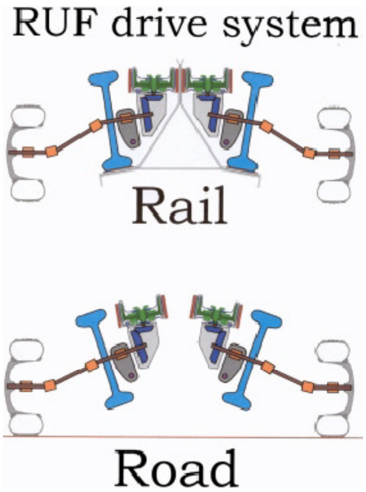


Figure 4.8: RUF drive system

(Source: http://www.ruf.dk/files/index.htm)

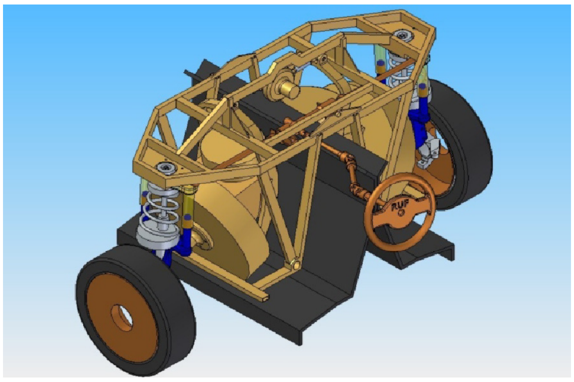


Figure 4.9: RUF drive system

(Source: http://www.ruf.dk/files/index.htm)

4.6. RUF Energy

The air resistance of single driving vehicles is high because of the vortices behind the vehicle. By close coupling the vehicles this can be reduced. The vehicles are built in that way so they can be coupled very easily. Making a train of the vehicles will reduce air resistance.

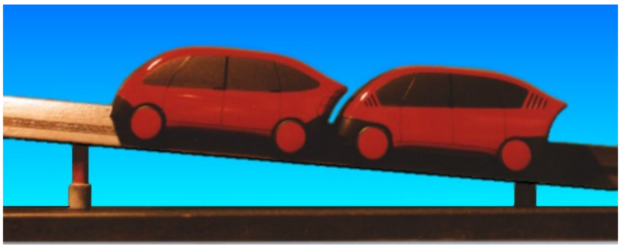


Figure 4.10: RUF train (Source: http://www.ruf.dk/files/index.htm)

The Laboratory for Energy Technology at the Technical University of Denmark made calculations about the air Resistance. According to these calculations the air resistance of 10 RUF vehicles driving at 100km/h closely coupled will be reduced by a factor four.

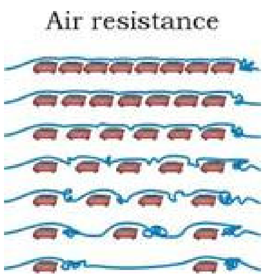


Figure 4.11: Air resistance RUF

(Source: http://www.ruf.dk/files/index.htm)

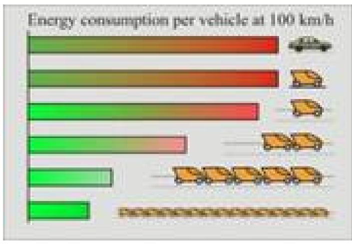


Figure 4.12: Energy consumption vehicles

(Source: http://www.ruf.dk/files/index.htm)

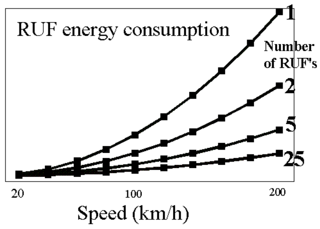


Figure 4.13: Energy consumption RUF

(Source: http://www.ruf.dk/files/index.htm)

"The special rail brake of the system makes it possible to use rail wheels with very low rolling resistance " [Jensen 2008].

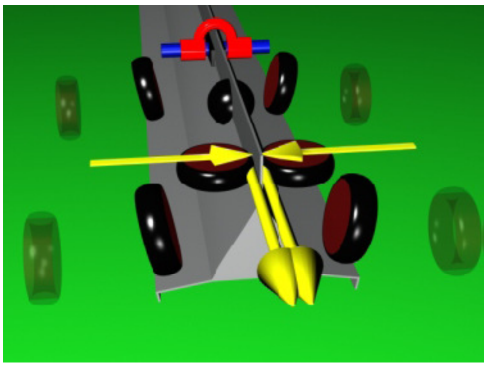


Figure 4.14: Brake system (Source: http://www.ruf.dk/files/index.htm)

4.7. Process

1. Charging the battery at home

2. Drive on the road to the nearest place to adapt to the monorail

Figure 4.15: RUF on the road (Source: http://www.ruf.dk/files/index.htm)

3. Adaptation to the monorail

Figure 4.16: RUF on the switch (Source: http://www.ruf.dk/files/index.htm)

4. Become part of a RUF train

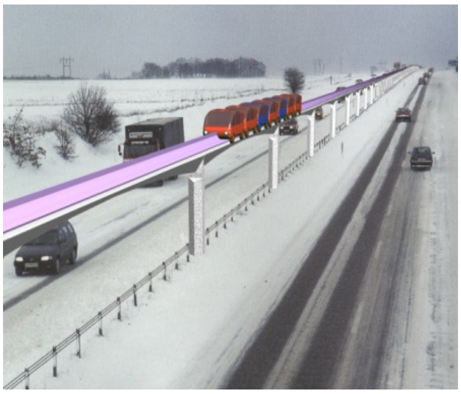


Figure 4.17: RUF on the monorail (Source: http://www.ruf.dk/files/index.htm)

Battery charged because of the adaption to the monorail

5. Approach monorail exit

6. Drive 30km/h to leave the monorail

7. Drive on the road to reach final destination

8. Charge your battery at destination

4.8. RUF Range

Within the RUF system there are several types of vehicles. From large vehicles for 25 passengers to four person RUF cars and the smallest in range being one person.

4.8.1. Mega-RUF

The Mega-RUF is an electrical bus for 20 to 25 passengers. In this bus ten people sit next to each other on one side of the bus, just like it is shown in Figure 4.18.

Figure 4.18: Mega RUF (Source: http://www.ruf.dk/files/index.htm)

4.8.2. Maxi-RUF

Figure 4.19: Maxi-RUF on the monorail

(Source: http://www.ruf.dk/files/index.htm)

Figure 4.20: Maxi-RUF on the road

(Source: http://www.ruf.dk/files/index.htm)

The Maxi-RUF is also an electric bus. It can carry ten passengers. There are five seats on each side and one seat for the driver in the front. The Maxi-RUF is 7 m long, 2 m wide and 2 m high.

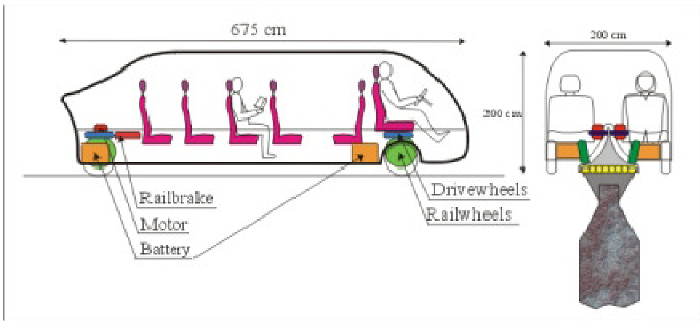


Figure 4.21: Dimensions Maxi-RUF (Source: http://www.ruf.dk/files/index.htm)

4.8.3. Midi-RUF

The Midi-RUF is more a family vehicle. It can carry five people. Three seats are on the right side and two are on the left side. One of the seats is used by the driver. This vehicle is 5 m long, 2 m wide and 2 m high.

4.8.4. RUF

The RUF is most similar to a normal car. It can carry four people. Two in the front and two in the back. The RUF is 3.50 m long, 1.75 m wide and 1.65 m high. On the road it is possible to drive 80km/h. On the monorail the RUF can reach a speed of 150km/h.

Figure 4.22: RUF on the road

(Source: http://www.ruf.dk/files/index.htm)

Figure 4.23: RUF on the monorail

(Source: http://www.ruf.dk/files/index.htm)

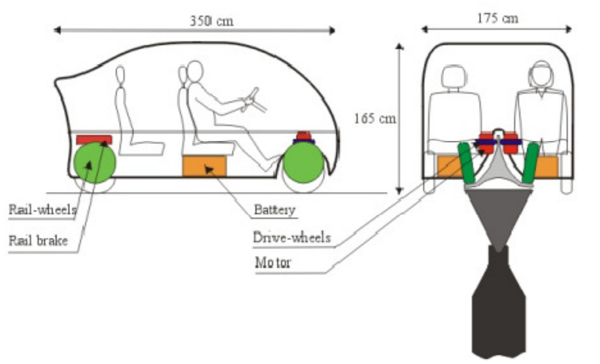


Figure 4.24: RUF dimensions (Source: http://www.ruf.dk/files/index.htm)

4.8.5. Nano-RUF

The Nano-RUF is a one-person mobility vehicle that can be adapted to the monorail like all the other RUF vehicles. The Nano-RUF should be a very compact vehicle. It can drive about 10 km on the road before entering the monorail. Then on the monorail the battery will be charged. After leaving the monorail it can drive again about 10 km to arrive at the final destination. It will only need a small battery, which utilizes less space. The driving system will be different than the system used in the other RUF vehicles.

4.8.6. Other Systems

Giga, Mini and Micro RUF's are not yet defined. So there is no information about dimensions and the number of person that can be carried.

4.9. Summary

This chapter gave an overview what the RUF system is, e.g. the dual mode system. The different RUF vehicles were described. Not every vehicle could be discussed because it is still work in progress. Our task for the project is to describe and dimension the Nano-RUF.

5. Methods

This chapter describes the most important methods and techniques used during the project. It is firstly about general methods like brainstorming and morphological chart, secondly about tools to organise and monitor the group progress like Work Breakdown Structures, Gantt Chart and Responsibility Matrix. Finally it is about the use of a questionnaire and a survey.

5.1. Research and Innovation Tools

This section shows the use of systematic innovation tools like brainstorming and the morphological chart.

Four brainstorming, four main rules were used: first to generate as many ideas as possible, second to avoid criticizing any of the ideas, third to attempt to combine and improve the ideas and last, to encourage the generation of wild ideas [Litchfield 2008]. Appendix 3.1 shows an example of brainstorming of the question at the beginning of the project, “which aspects have we got to consider for the Nano-RUF?”

The main goal of brainstorming was to get an overview of the aspects that should be considered for the project. It was important to get as many ideas as possible and then evaluate them afterwards. By considering and glimpsing all the ideas the team benefitted from cognitive stimulation [Ferreira 2011, Landis 2008].

Brainstorming was often used, for example when the group analysed which motor concepts could be used like a Segway based motor, electric motor, in-wheel-motor, etc.

Another tool used for the project was the morphological chart. It was used to generate and evaluate alternative approaches. This was chosen, because it was applied in the beginning of the idea generation phase and therefore it fitted perfectly with the project. The aim was to generate a complete range of alternative possibilities for the different functions through a systematic analysis of the configuration that the Nano-RUF might take [IfM n.d.].

Firstly the different functions of the Nano-RUF were identified: e.g. it must have a motor that can drive the vehicle on its own. Focussing on essential features of the product and trying to use an appropriate level of generalisation. Afterwards each function itself was considered and the aim was to find all the possible solutions. The group tried to think outside the box and consider different solutions for a task. This was put together in Table 5-1 and the results can be seen on the following page.

First thoughts were focussed around a two wheel Nano-RUF based on the Segway concept. After some literature review, sketches and discussions, it was decided to develop a 4-wheeled vehicle. Thoughts were also developed about a 3-wheeled concept, but it did not fit with the monorail system. This example shows how the morphological chart for different functions was applied to the project.

Combined with mechanical information it was finally decided to use four wheels and not two like a Segway. This approach is the one that was applied for all components, even if some became more important than others. Whilst allowing room for change. It was a very useful starting point for the different functions and options.

	OPTION 1	OPTION 2	OPTION 3	OPTION 4
Navigation system	Internal RUF system	External device		
Wheels	1	2	3	4
Motor/Engine	Synchrony electric	DC – Electric		
Brakes	Drum	Disc	Hydraulic	Carbon ceramic
Suspension	Independent/ non independent	Coils	Shock absorbers	Anti-sway and track bar
Monorail	None	Above link	Below link	
Chassis	Monocoque	Tubular frame		
Cabin	Open	Closed	Convertible	Semi
Battery	Lithium	Lead		
Lights	LED	Xenon	Halogen	Energy efficient bulb
Transmission	Single gear	Dual Gear	Several Gears	
Seats	0	1	2	
Passengers	1	1+1 (1 adult and 1 child)	2	
Passenger layout	Parallel	Tandem	Facing	Standing/Laying
Power source	Monorail	Grid	Solar	Turbine

Table 5.1: Morphological Chart

One of the most important methods was research. Important sources of information were the library, databases, books and articles. It was also necessary to research into some available vehicle concepts on the Internet from car manufacturers and other companies. These often spent a lot of money to develop their concept vehicles, so it was often helpful to use parts of their concepts for the Nano-RUF. Very similar to reverse engineering. The two concept cars Renault TWIZY and Peugeot BB1 were helpful to get a better feeling and calculate numbers about the weight. This can be seen in the Figure below.

Figure 5.1: Research into concept papers, similar reverse engineering

5.2. Project Organisation Tools

Three tools were used for organizing the project work and monitoring the progress of the group: Work Breakdown Structure (WBS), Responsibility Matrix and Gantt Chart.

The Work Breakdown Structure was a very good starting point to see which tasks the group wanted to solve, to get a better structure how they are connected and how they can be separated. An example of the first work breakdown structure is shown in Figure 5.2.

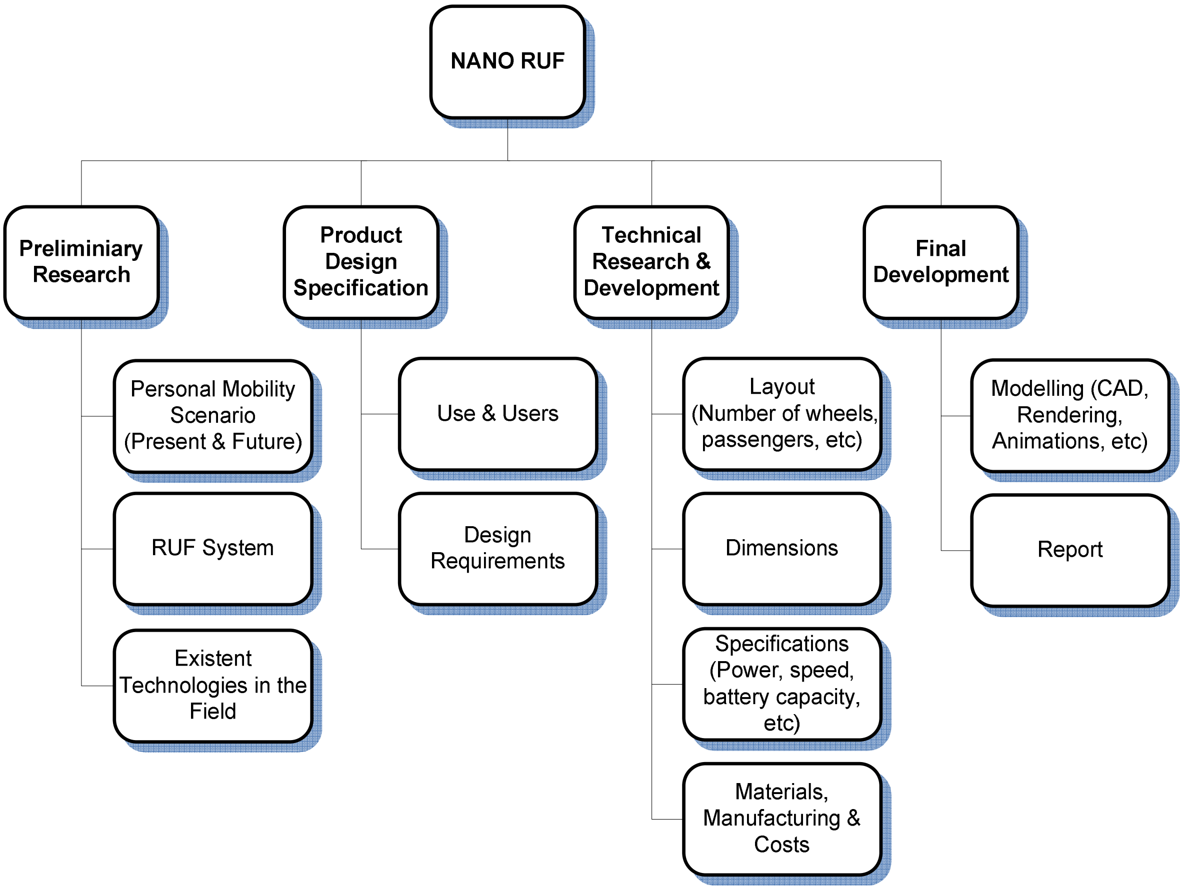


Figure 5.2: Work Breakdown Structure

The group's adoption of the Responsibility Matrix is explained. The group uses one Responsibility Matrix for the whole project (Appendix 3.2). Therefore additionally to the matrix a task and work period date was defined, which is shown in Figure 5.3 below.

WBS \ OBS	Kaat	Chris	Tom	Josep	Jorge	Comments
Title Page			R			
Content Page			R			
Background	R				S	
Aims etc.	R				S	
Group / Team	R				S	
Ruf in General	S				R	
Methodology / Structure		R		S		
RM for Interim Report		R				
Gantt Chart for Interim Report		S		R		
RM for whole Project		R				
Gantt Chart for whole Project		S		R		
WBS, Research and other techniques		R		S		
Results	S	S	S	R	S	
Specifications				S	R	
Sketches	S		R			
Initial Concept	S	S	R	S	S	
Project Plan	S	S	S	R	S	
Conclusion	S	S	S	R	S	
References	S	R	S	S	S	
Completing the final Report Version	S	S	R	S	S	

Task	Work period
Title Page	22/03
Content Page	22/03
Abstract	22/03
Background - Problem Statement/Aim - Group/Team - Ruf in General	01/03 – 08/03
Methodology / Structure	
- Gantt Chart and RM for Interim Report	01/03
- Gantt Chart and RM for whole Project	17/03 - 21/03
- WBS, Research and other techniques	01/03 – 08/03
Results	
- Specifications	01/03 – 18/03
- Sketches	01/03 – 18/03
- Initial Concept	18/03
Project Plan	21/03
Conclusion	22/03
References	01/03 – 21/03
Completing the final Report Version	22/03 – 23/03

Figure 5.3: Responsibility Matrix for the Interim Report

This tool is very useful to divide tasks, to have clear responsible people, to balance the workload of every team member and for internal communication of group progress.

Another similar tool is the Gantt Chart. The following Figure 5.4 illustrates the schedule of the project and visualizes the upcoming tasks with a start and a finish date for every section. The connection and dependency between activities is represented in the chart.

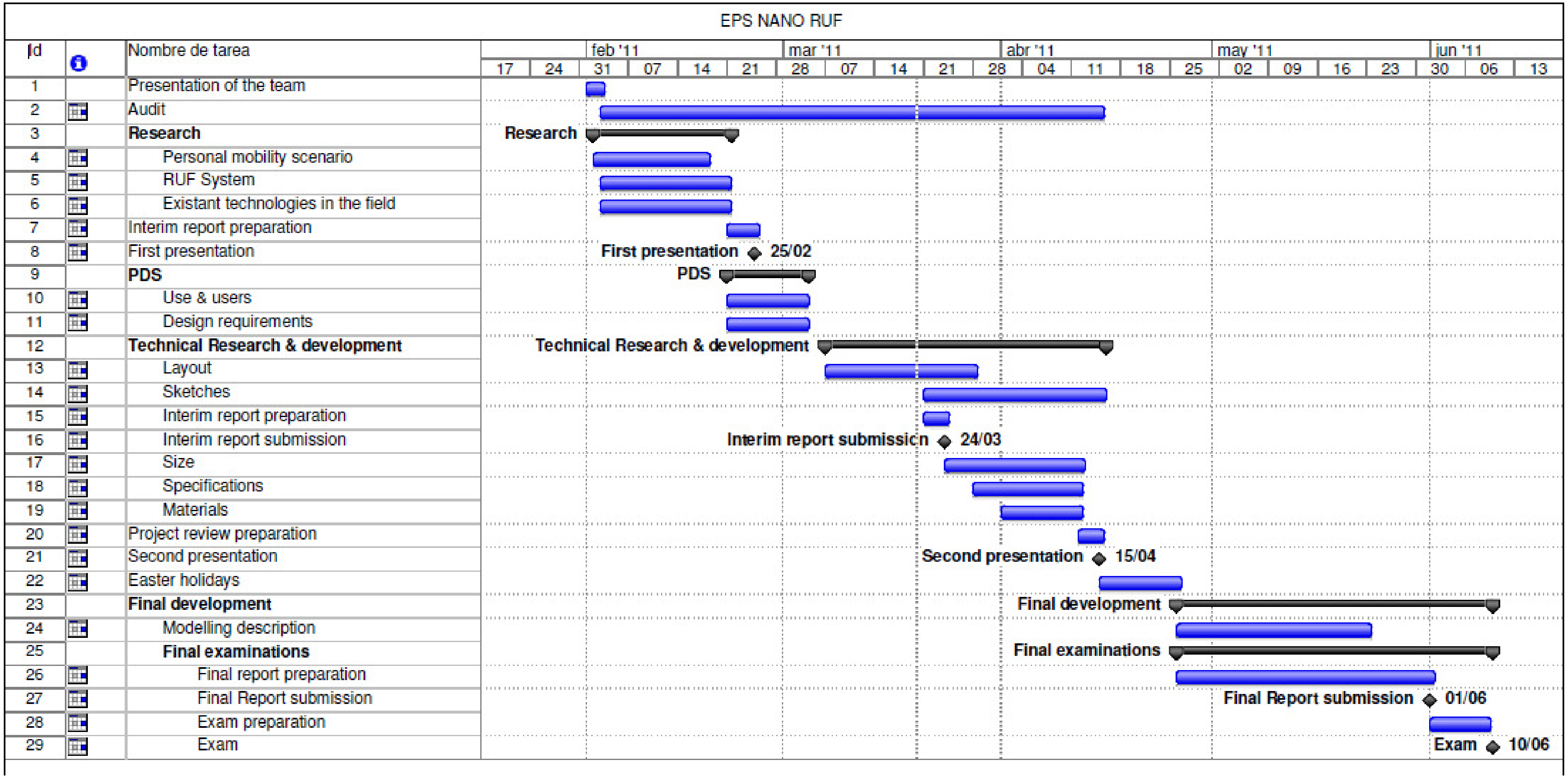


Figure 5.4: Gantt Chart EPS Nano-RUF

5.3. Summary Research, Innovation and Project Organisation Tools

The description of brainstorming and the morphological chart explains the method the group tried to take to solve problems in a structured, systematic way. Both were completed using teamwork and the whole group gave their input using their own knowledge. The morphological chart was very useful because each group member had a different major subject qualification. So a good overview of possibilities was obtained. These three tools: WBS, Responsibility Matrix and the Gantt chart, were very useful tools for the group. They helped to split tasks, to give specific tasks for every team member and to see the progress of the project.

5.4. Personal Mobility Questionnaire Results

To gain an insight for the target market the group created a questionnaire with specific questions that provided sufficient data to determine some of the parameters for the Nano-RUF. The Questionnaire was made with an Internet based format and was sent out to friends and colleagues of the group. Over 80 responses were collected to give an accurate distribution of data.

See Appendix 3.3 for an example of the questionnaire.

The first question was to set an age range. The results show that 98% of people who answered the questionnaire were between 18 to 29 years old, and only 2% were 30 to 59, with a distinct lack of persons over 60. This was probably due to the age range of the group being below 29, therefore it was sent out to friends and colleagues of a similar age. The collection source “Facebook”, was also a contributing factor to low age range as the older generation tend not to facilitate themselves with the website. The age distribution provides an unfair sample of the population however; it could be argued that the Nano-RUF is a future project aimed at the future generation. Therefore collecting a younger sample would be more beneficial to the data in the long term of the project.

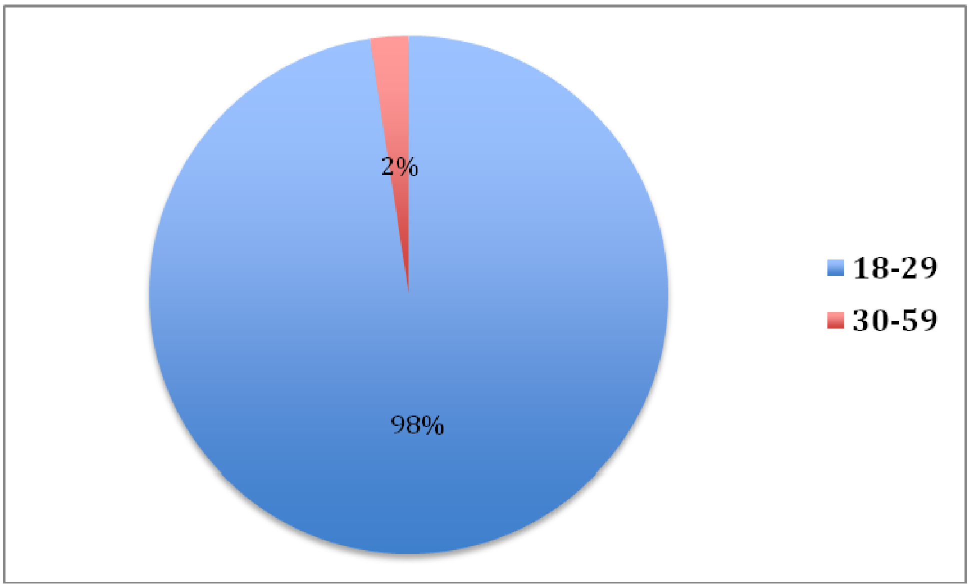


Figure 5.5: A graph to show the percentage of age ranges that filled out the questionnaire

The second question was concerned with the method of travel that the population sample most commonly used. The majority of the sample used public transportation and roughly a quarter drove a car. 2% more people rode a bicycle than walked and only a small fraction on the sample rode a motorcycle. The conclusion that was drawn from the results is that people choose public transport mainly because of the low cost, whereas the people who drove a car preferred the comfort of their own vehicle and could afford the running costs. It was interesting to see that 36% of the sample preferred to cycle or walk and use physical energy. 10% more people used public transport than drove a car. This was relevant to the distances travelled (see Figure 5.8). This showed that the largest market was within the public transport sector however there was still a large enough market within a quarter of the population for private vehicles.

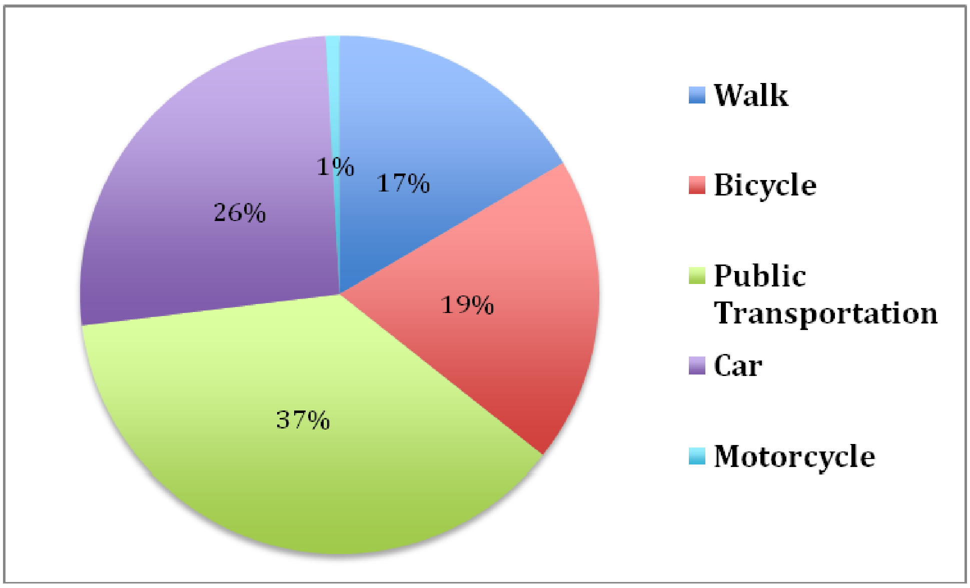


Figure 5.6: A graph to show percentage distribution of various methods of transportation used by the population sample

Now that the most common methods for transportation were established it was necessary to determine the reasons for travelling and the typical distance of the journeys. So the next question was targeted at finding the reasons why people travel on a daily basis. The graph below shows that 67% of the population sample commute for work or education purposes. This means that the proportion would be the same five out of seven days during the week. 17% travelled for sport or leisure and 14% travelled to the shops. This meant the largest market was for the population that made the daily commute to work or university. This also meant that the RUF did not need a lot of space. Just enough to store a brief case or rucksack. Only 1% of the sample used transport to take a break and another 1% skipped the question for unknown reasons.

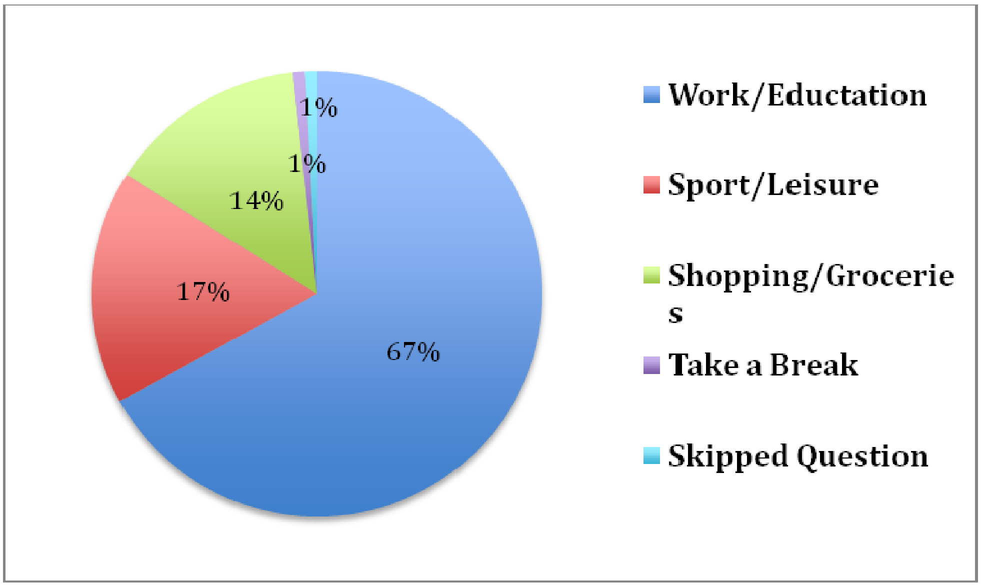


Figure 5.7: A graph to show the percentage distribution for the reasons of transportation

The fourth question in the questionnaire was designed to discover the distances usually covered by the average journey. The results showed that almost an equal amount travelled under 10km and 10-30km, with only 4% more travelling the shorter distance. This sparked questions among the group about the size and duration of the Nano-RUF's batteries and the limitation of speed upon them. The original brief described the Nano-RUF having a battery large enough to carry the vehicle 10km. This new evidence showed that the vehicle needed enough power to last 30km. However it was argued that the Nano-RUF only needed to travel 10km before it could link with the monorail where the battery would be replenished. The group decided that the larger duration of 30km was better due to the average journey was never a simple straight line of 10km. It is possible to estimate that the 36% of people who walked or cycled were inside the 10km distance and the population that commuted by car drove the longer distance.

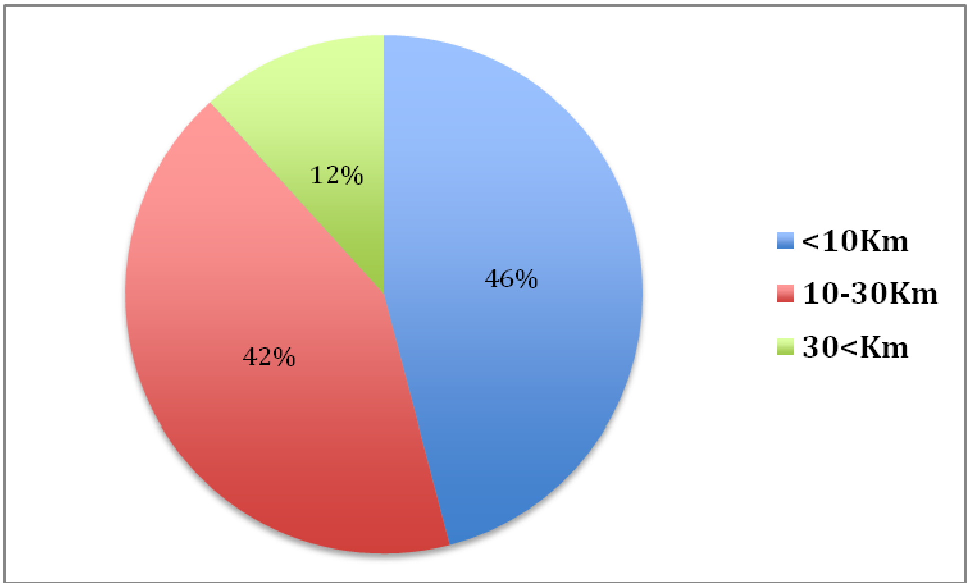


Figure 5.8: A graph to show the average distance travelled by the population sample for an average journey

Perhaps the most important question was whether the RUF needed enough space for additional passengers. This was discussed at length between the group. Some members made the case that parents might need a space for a child to be carried for such instances like being driven to and from school. Other members of the group argued that if that was the case the parent would buy a Mini-RUF or a RUF car. The results that were collected ultimately made the decision. 76% of the sample did not carry a passenger with only a quarter that did. This showed that the largest area of the market was for a one-person vehicle. This also meant that the overall dimension of the RUF would be a lot smaller which would mean less weight and therefore less power required by the battery. So a smaller more efficient vehicle was the main aim for the group.

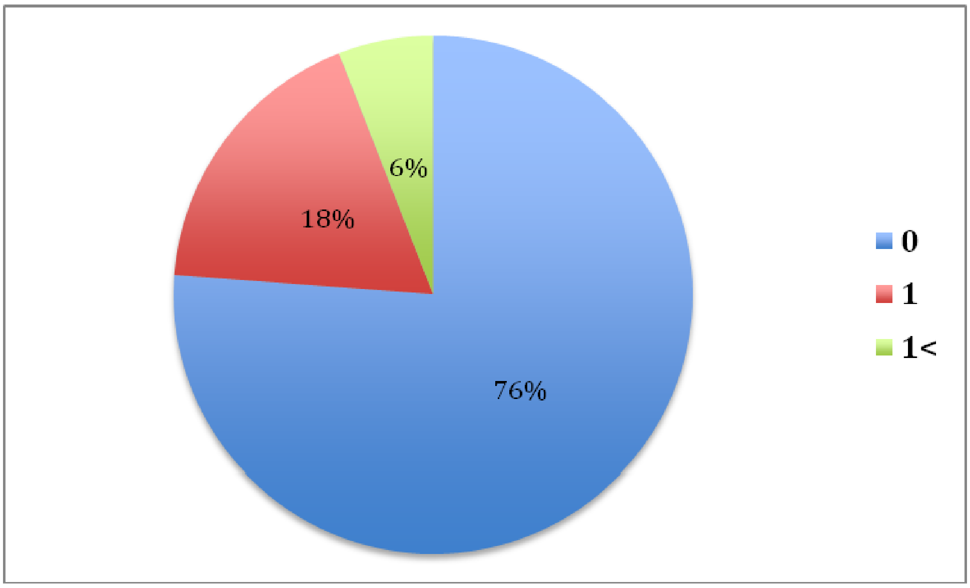


Figure 5.9: A graph to show the population that carried passengers on their average journey

The last question was not really useful for designing the parameters of the Nano-RUF but was used to gain a general market interest, as it shows a large proportion of the sample showed an interest in a new cheap method of transportation. Only 7% did not show an interest for unknown reasons. It could be estimated that the 7% preferred the low cost of public transport, the pleasure of walking, cycling or simply did not care.

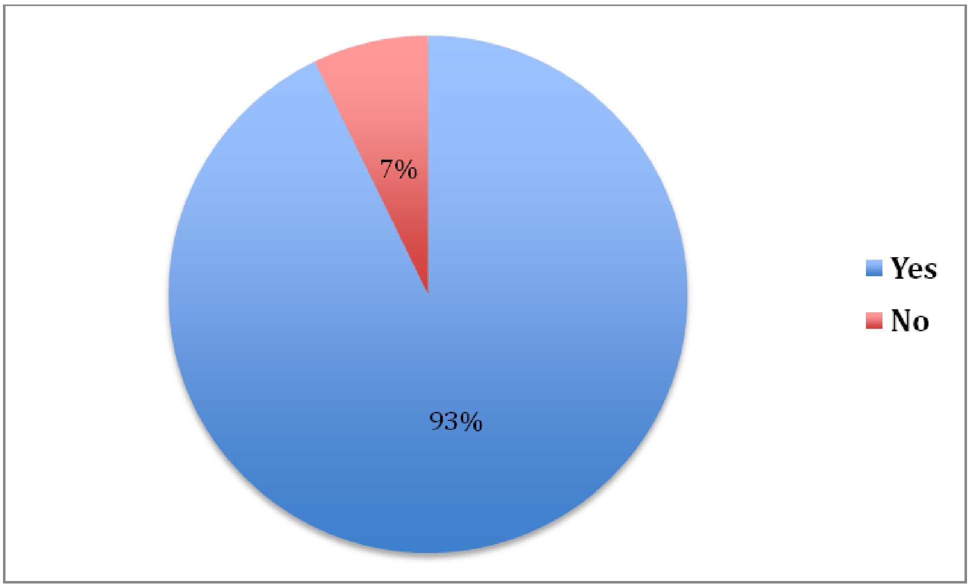


Figure 5.10: A graph to show the population interest in a more efficient method of transport

5.5. Questionnaire Summary

The Results that were collected from the population sample were extremely beneficial to the group. It helped to determine certain aspects or parameters for the RUF's design and backed up decisions with evidence. For example the collated data helped decide the size of the vehicle, 76% of the sample did not need to carry a passenger so the vehicle would not require space for a passenger. Allowing it to be smaller. It was helpful in deciding the required size for the batteries, the smaller size required less power but the information gathered showed that a larger battery and longer duration was required for journeys up to 30km. Overall the questionnaire helped the group to gather a more defined idea of the target market for the Nano-RUF. It was a successful process that produced valuable results for Nano-RUF and the whole RUF system in general.

5.6. Personal Mobility Survey

Beside the questionnaire a survey was completed to get a better idea about the potential market for the Nano-RUF.

The survey is based on counting the number of vehicles and the occupants. Because the group spent a lot of time discussing different passenger and seat options for the Nano-RUF like one-seater, 'one plus one'-seater or even a two seater. The survey was started during the decision process. Now it backed up the decision for a one-seater.

The survey resulted in more detailed information about the possible number of customers for a single passenger Nano-RUF. For a first impression the results are quite useful due to the high number of counted vehicles. There will not be a detailed analysis about the market size for the Nano-RUF, right now it is reasonable to be satisfied with the data quality.

Before the results are shown, underlying circumstances were set by the group for the counting to get comparable quantities. They are listed below:

- Even if the group members were counting on different roads, they all had to meet the criteria for a two-lane road.
- Every counting was done during the rush-hour; therefore there were many commuters in the data sample.
- The group members counted all cars and motorbikes on two-lane roads. Beside cars and motorbikes vehicles like lorries and other commercial vehicles were not considered.

In the Appendix 3.4 one can see the exact numbers and the calculations, whereas the graph in Figure 5.11 shows the analysis of data where it can be seen that 75 % of people are driving alone and just in 25% there were more than 1 passenger in the vehicle.

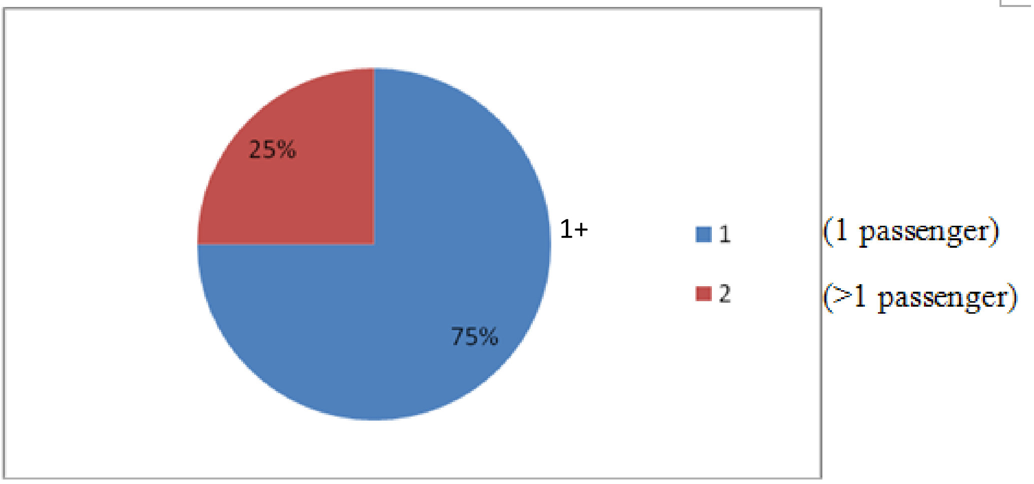


Figure 5.11: Results of the survey

Therefore the first evaluation reveals clearly that a single passenger should have a large market size.

Although the results of the survey seem pretty obvious, the group will indicate some limitations. If 75% were driving alone in the car, it could happen that earlier or later on in the journey more people could enter the car. As the Nano-RUF will not have a car boot or much space to put the shopping bags, a larger car can be needed for some people for this reason, or for people with a dog.

The questionnaire and the survey were very useful tools to define the target market. The best product cannot be sold if there are no potential customers. Therefore this was a critical part of the project.

6. Business Considerations

6.1. Framework Conditions

Andrew Andrusko wrote in 2010 for the American Planning Association: “Changes in energy technologies have once again sparked an interest in dual mode transportation, a concept that until recently was thought implausible”. Three basic influencing factors; oil price, climate change and urbanisation are depicted in the following part because they influence the development and implementation of the Nano-RUF.

6.1.1. Oil Price

As the oil demand is expected to increase due to the need of emerging markets and the supply cannot scope this, the oil price has been increasing [Mason 2011]. Additionally unstable political conditions in the largest oil extraction regions like the Middle East are the driving force for increasing the oil price. Although the future oil price is hard to predict accurately, most experts are convinced of a raising price due to the market mechanism larger demand than supply [Ryan & Lidderdale 2009]. The following Figure shows a concept with three different scenarios done by the EIA – the U.S. Energy Information Administration. One with a low oil price, one with a reference price and one with a high oil price. This model expects a moderate and conservative price increase, but it is important to note that the future prices are shown in real 2009 dollar prices, which mean that the actual prices are higher due to inflation.

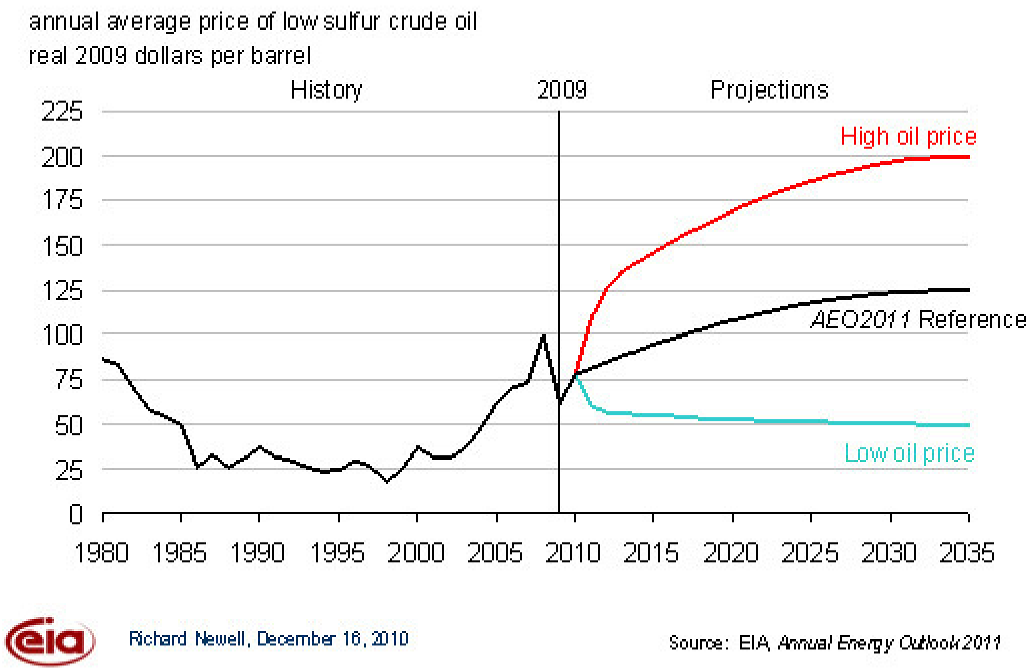


Figure 6.1: Oil Prices Scenarios I (http://www.eia.doe.gov/neic/press/images/2010_13_figure4.jpg)

Another model is shown in the next Figure, done by Weeden & Co. Hereby it is important to note, that the prices are shown in the prices of the year, so the $300 price in 2020 will be about $225 in today's dollars according to the analyst Charles T. Maxwell from Barron's - the Financial Investment News which covers market developments and relevant statistics [Strauss 2011].

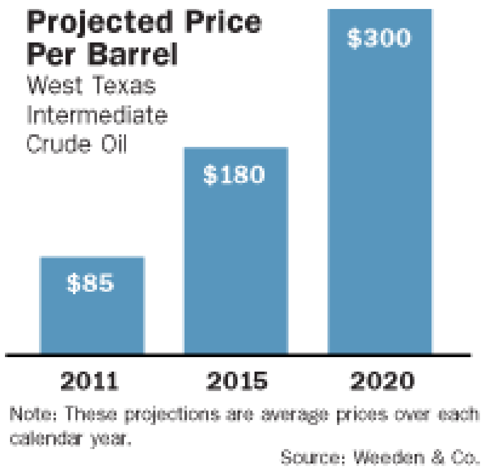


Figure 6.2: Oil Price Scenario II

(http://online.barrons.com/article/SB50001424052970204098404576130370708044708.html?mod=BOL_hpp_popview#articleTabs_panel_article%3D2)

The peak oil model consists of the point in time when the maximum rate of global oil extraction is reached, after which the rate of production enters terminal decline (Appendix 4.1). In the discussions about this model a price about $500 is assumed to be reached soon and this would provoke big changes [Helman 2010, Stier 2008].

In summary a rising oil price will be a subject to change the current car transportation. The Nano-RUF will benefit from high oil prices.

6.1.2. Climate Change and Regulations

Another important aspect is the climate change and that regulations are becoming more stringent. The progressive climate change is forcing the governments to act in this field, and even if the last summit on climate change was not a great success, the need for changes is omnipresent. Therefore, a new climate friendly transportation vehicle like the Nano-RUF will profit from the need for a more sustainable transportation systems. The following Figure shows the allowed CO2 emissions. As can be seen, Japan and Europe continue to lead the world with the most stringent passenger vehicle greenhouse gas and fuel economy standards. The California regulations are expected to achieve the greatest overall reduction in greenhouse gas emission in the world in the next few years.

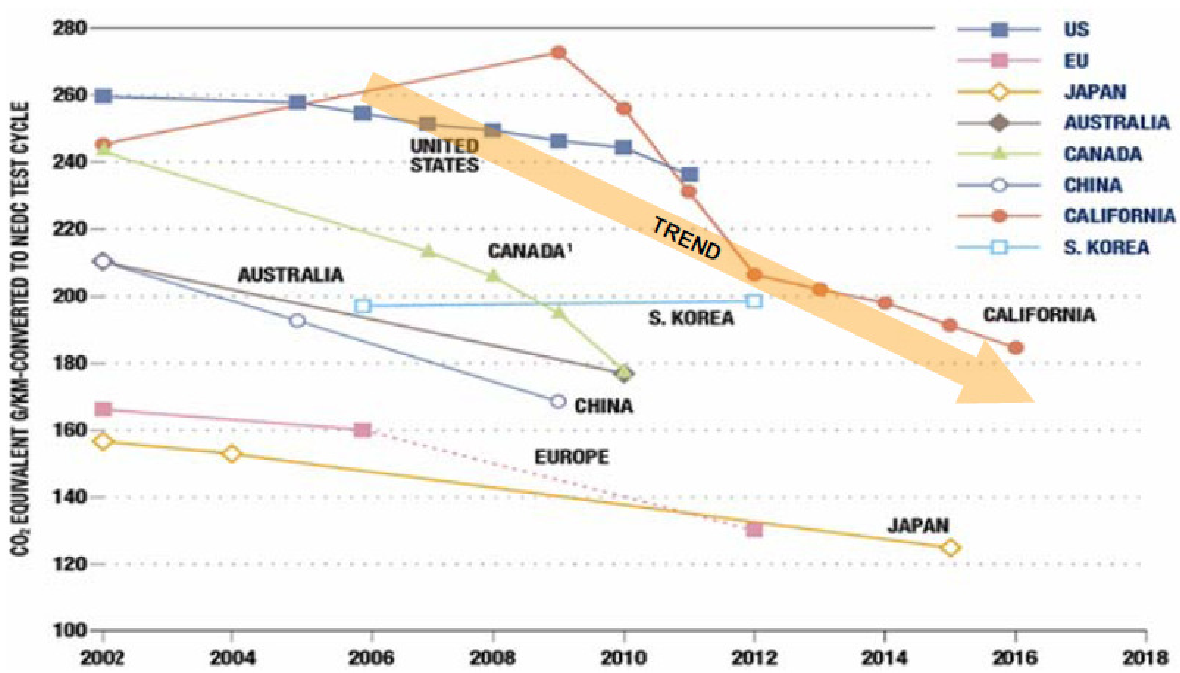


Figure 6.3: Market CO2 Regulations (Source: [Kodjak 2007])

This shows the rising concern about environmental issues and car pollutions. This development will increase and maybe lead to additional fiscal policies to promote technology innovation like the Nano-RUF. For example the European Commission launched a new white paper about future transportation in the end of March 2011. It was concluded that "the Commission will prepare appropriate legislative proposals in the next decade. The Commission will ensure its actions increase the competiveness of transport while delivering the minimum 60% reduction of GHG emissions from transport needed by 2050" [EU Commission 2011].

6.1.3. Urbanisation

The third identified main aspect lies in growing cities and Urbanisation. As the big cities are growing, congestions and the problem of building new highways to the city centre due to the lack of free space are rising. For example, about 80% of the US population live in cities and suburbs [Hodgson n.d.].

The next Figure shows the Urbanisation trends for 2030. The percentage of urban population is growing and therefore the cities are subject to changes in the transportation system.

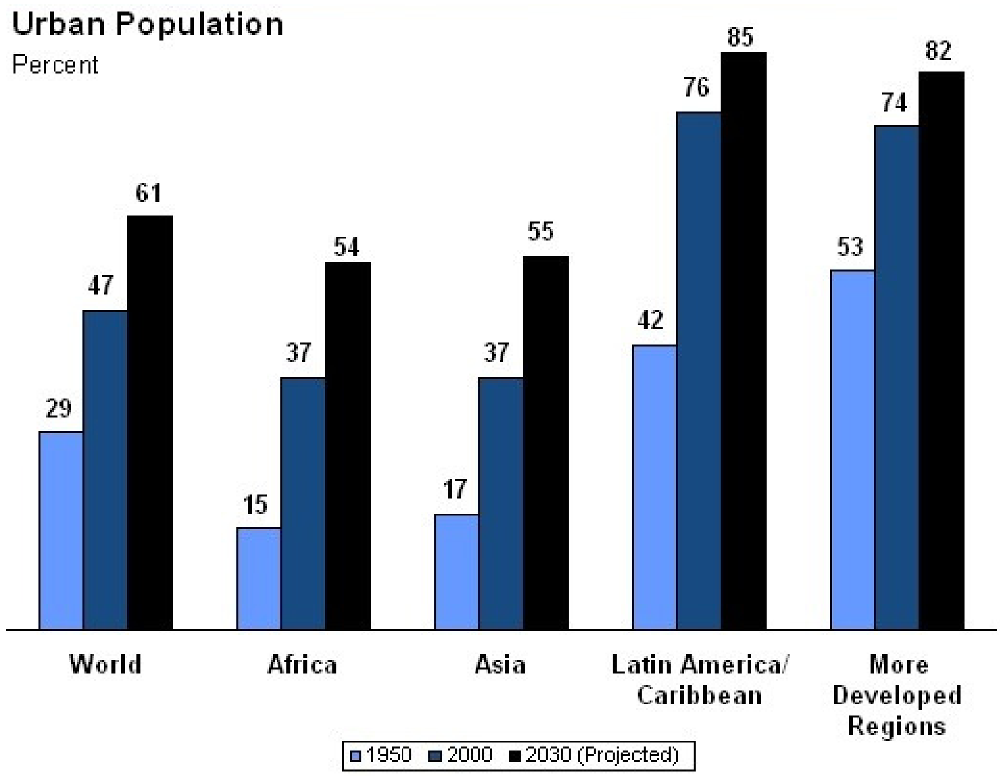


Figure 6.4 : Trends in Urbanisation, by Region (Source: [United Nations 2004[])

Therefore the Nano-RUF is very interesting especially for commuters and people who go from suburbs to the city centre or across it. As the Mega-RUF for example would be a possibility for collective transportation (public transit), the Nano-RUF is a possibly solution for individual transportation.

Already nowadays, many large cities are restricting access to their inner core, like London, or forming "environmental zones" as in Germany. In a KMPG study (Appendix 4.2) seventy-six percent of respondents believe that urban planning will influence future vehicle design, which again points to a need to produce city-friendly cars and embrace alternative mobility solutions [KPMG 2011].

6.2. Business Models

6.2.1. Gardener Life Cycle

To get a better impression of the assessment of RUF, the Gardner Life Cycle is a very helpful graphic tool. Figure 6.5 shows this graph including estimation where the group sees RUF.

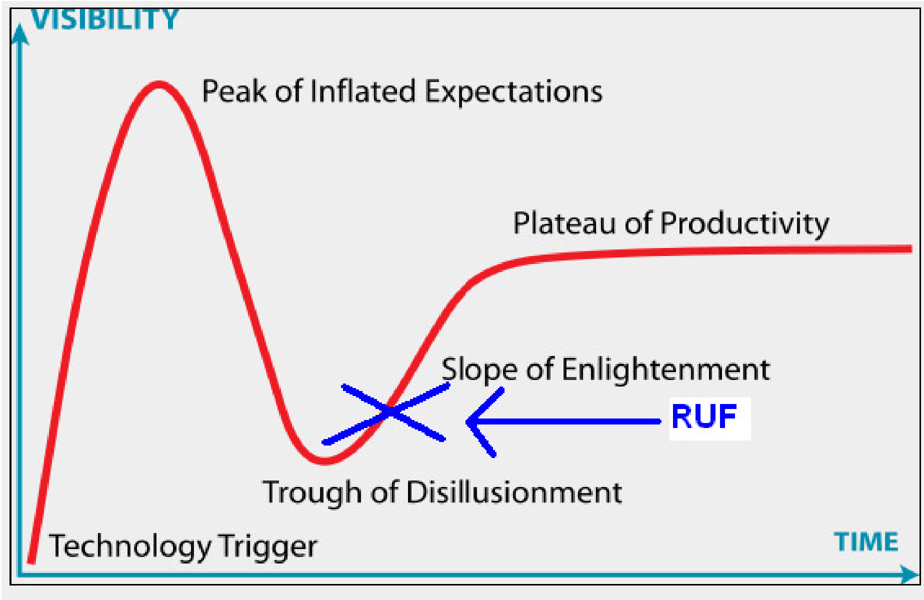


Figure 6.5: Gardener Life Cycle and RUF Assessment (Source: http://prsawis.files.wordpress.com/2010/10/gartner-hype-cycle.png)

As the graph shows, there are five different phases: Technology Trigger, Peak of Inflated Expectations, Trough of Disillusionment, Slope of Enlightenment and Plateau of Productivity. On the axis of abscissa is time or maturity of technology or product, whereas on the axis of ordinates the visibility is shown.

The first phase, the technology trigger, was shortly after the development of the RUF idea around the early 1990s. It was followed by positive publicity, although the commercial viability was unproven at that time. The second phase, the peak of inflated expectations arrived soon after that. There were many press releases, especially in the USA. After that the implementation of the technology failed due to the missing verification. The missing verification was due to the missing money to start. The phase trough of disillusionment was reached. Right now, RUF is still on this phase, shortly before the slope of enlightenment. The maturity of the RUF technology is increasing, the technology is getting better, and the product range increases. For example, from offering not only RUF cars but also Maxi-RUFs and the development of Nano-RUF. When the mainstream adoption starts to take off, the plateau of productivity is going to be reached. It is important that the benefit of the RUF technology and the RUF system is become widely demonstrated. Instead it is necessary to get money for a test and verification of the system, so that it can be accepted and then used in the praxis [Gartner n.d.].

6.2.2. Radical Innovation

Today the transportation sector is characterised by incremental innovations. That means that just small improvements made, for example when the car industry reduces the $CO2$ emission slightly with new cars. Even if these are needed and positive, they are not enough to solve the problem. A so called radical or disruptive innovation is needed. This is characterised “not by doing it better, but by doing it differently" [Anthony et al. 2008]. The Nano-RUF is a potential radical innovation.

Incremental Innovation	**Radical Innovation**
• **exploits existing technology** • **low uncertainty**	• **explores new technology** • **high uncertainty**
→ improvements in existing products & processes	**→ development of new products & processes**

Table 6.1: Incremental vs. Radical Innovation

6.2.3. S-Curve Model

There are a lot of traffic problems right now and this development is increasing as the challenges are huge. Although all the involved parties try to solve this problem, most of them stick to the traditional solutions. Car manufacturers and supporters want to build more highway lanes; the train companies want new train lines and Metro systems. As the following S-Curve Model shows the current existing technology curve is right now more advanced than the Nano-RUF technology. For example in terms of production costs. However, the change to the emerging Nano-RUF technology will give payback because the new technology has a much higher potential income. Even if the beginning production costs are not competitive to normal cars, in middle- and long-term the Nano-RUF can achieve the same level.

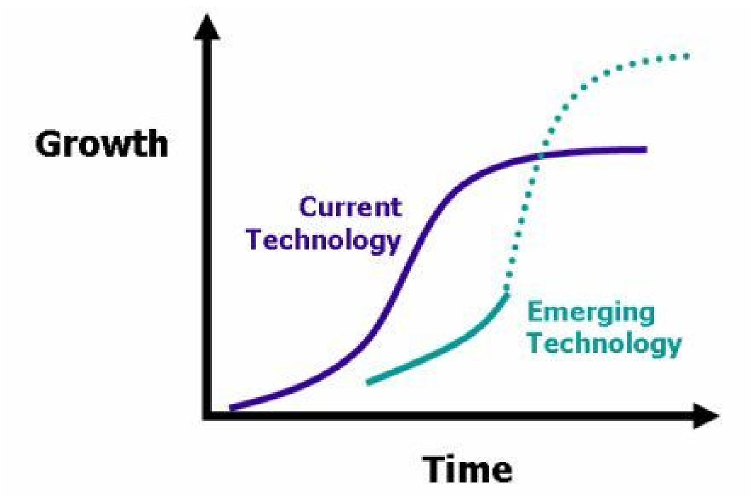


Figure 6.6: S-Curve model (Source: http://elsoc.wikia.com/wiki/ELEC4122)

6.2.4. Summary

These three generally acknowledged and widely used business models show the academic approach of the group and can be used to clearly underline the need for a change towards a new system. The Nano-RUF technology can meet the new challenges and become a 21st century transportation system.

6.3. Nano-RUF Capacity

In this chapter some considerations about the capacity of the Nano-RUF are made. It is not useful to have just a large peak capacity if the comfort level is low. Frequent departures can produce a high capacity. A major advantage of the Nano-RUF compared to the road is that on the road large stopping distances are required. The group calculated the maximum capacity. Even if practically this capacity is not obtained, the theoretical number is important for comparisons.

Therefore some assumptions according to the RUF Capacity Report [Jensen 2010] are used, which are listed below.

Assumptions:

- Top speed on line: 150 km/h
- Switch speed: 30 km/h (= 8.33 m/s)
- Nano-RUF: 1 passenger in a 1,80m long vehicle
- Train length: 35m

There are two different possibilities: Firstly, the trains can be created on the monorail or secondly before access to the monorail.

For the first case; the trains are created on the monorail - the Nano-RUF vehicle accesses the triangular monorail at 30 km/h with a separation of 5m. This means ≈1.22 Nano-RUFs will access the monorail every second. That means that the capacity is 4410 vehicles and therefore seated passengers per hour per direction (Appendix 4.3).

For the second method; the creation of trains before access to the main line – the capacity increases decisively. 19 Nano-RUFs are connected to form one train. About every five seconds one of these trains enters the monorail per direction. The capacity is 14244 seated passengers per hour per direction (Appendix 4.4).

As the difference seems very large, the group suggests creating trains before access to the monorail during rush hours and on the monorail the rest of the day. During rush hour, when a lot of people are using the system, the people do not have to wait long to create a train.

The Nano-RUF should be able to build trains with the other RUF vehicles, even if the group did not study the aerodynamics specifically.

6.4. Cost and Price Considerations

Normally the costs of a product have to be analysed in detail. This is a very complex field and the group did not have the time to consider that part much, therefore just a few basic considerations were made.

There are different pricing options. Design a product which is superior to the current products, and then a higher price can be achieved. The customers will be willing to pay that price. Another possibility is to do a target pricing, which means to set a price and then design the product to match with the costs. For the Nano-RUF, the first possibility is chosen.

There are mainly two pricing strategies; the penetration pricing strategy and the skimming pricing strategy. For the Nano-RUF the price skimming will be chosen. That means that in the beginning the price will be high, but the Nano-RUF will be new, innovative and matches the customers environmental consciousness when it is launched onto a market. But additionally there can be public subsidies, because governments want to promote electric vehicles.

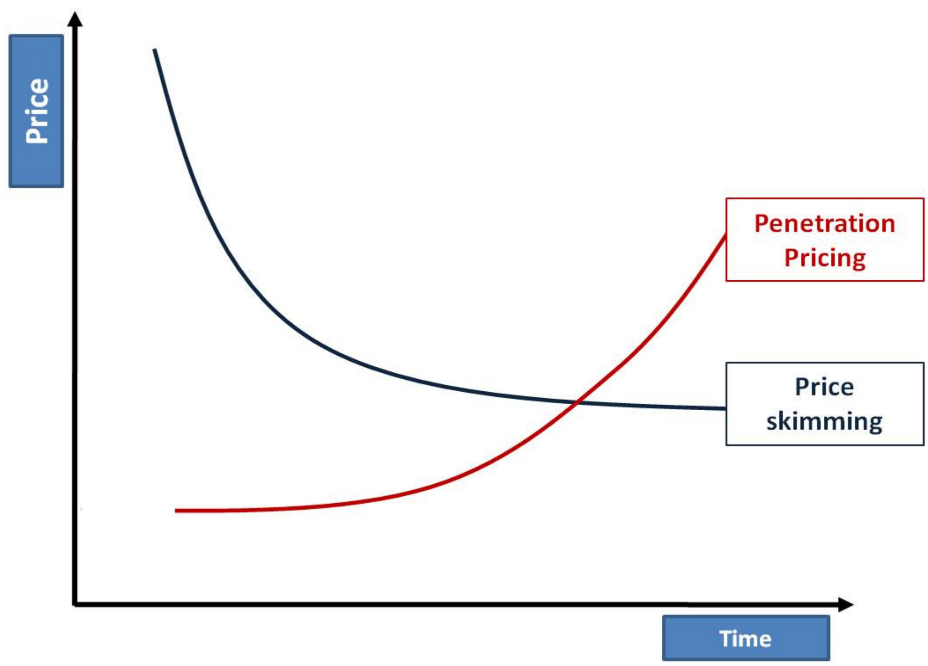


Figure 6.7: Pricing Models (Source: [RM 2011])

Buying or starting cost of the Nano-RUF system should be considered, so a life-cycle consideration should be done.

One aspect in which the group decided to go into further detail was the cost of battery technologies. This is a very critical part for electric vehicles. Although it is not that important for the Nano-RUF because it needs smaller batteries due to the monorail charging process. However it is a relevant cost to the driver. The following Figure shows an example battery and electrical machinery costs.

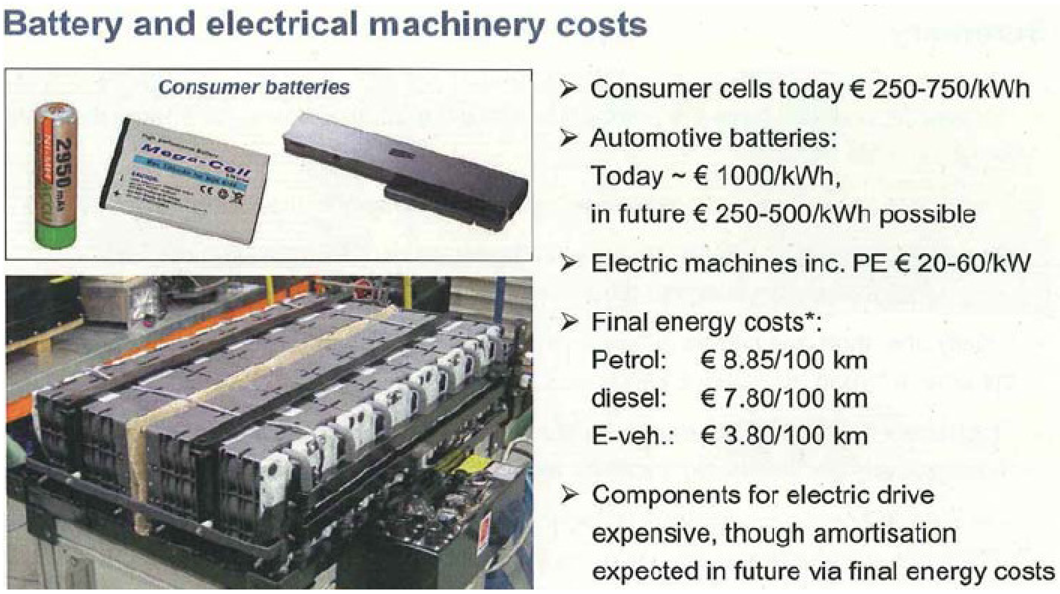


Figure 6.8: Battery costs (Source: [Koser 2010])

The intention is not to go into detail but to show that a lot of progress is made in the field of automotive batteries and the costs will decrease. The decrease is expected to be about the factor 2 or 4 of the current cost. The final energy costs are calculated for a electric vehicles. However, it must be calculated for the Nano-RUF separately, but to get a first impression the group decided not to delete this information. The group's supervisor gave the advice that RUF has contacts to Exide Industry, the biggest storage battery producing company in India, but the group decided that this part was not the focus of the group and therefore this topic is not further discussed.

6.5. Business Plan

After viewing the framework conditions, some business models and some brief cost considerations, this chapter is mostly about creating a Business Plan for the Nano-RUF.

6.5.1. Introduction

There are some different opinions about the sense and use of business plans. Sometimes technical engineers tend to attach little importance to the business part of a company. But the Panel Study of

Entrepreneurial Dynamics shows that "You're two and a half times more likely to get into business". The main reason is because securing funding almost always requires a formal plan. If a start-up company want a venture capitalist, commercial banks, governments or angel investors to invest money, they likely want to see a business plan [Henricks 2008, Hughes 2010].

To convince the investor a Business Plan is a helpful method. It is a comprehensive, written description of the business of an enterprise. As it is a crucial element in any application for funding, it should be complete, sincere and factual. Therefore the group made a first business plan version about the Nano-RUF. This could also be helpful to convince the government, because it is a very successful way to introduce a project and the need for an investor. As there are several templates for business plans (United Nations 2002, Business.gov.au 2011), which differ in some parts, the group decided to use the structure of the Business Plan template from the Danish Venture Cup, the largest entrepreneurship competitions in Scandinavia. Because of the popularity of a Business Plan in the U.S. and RUF's good connections to some partners there, it is another positive aspect. RUF International should try to convince SEED Capital Denmark, the largest venture fund in Denmark, that Nano-RUF is a green transportation system and therefore a promising 'Cleantech company'.

In this report, the Business Plan does not cover all facts, because some information, especially the technical specification and some images would just be a repetition of other parts of the report. Therefore the group decided to not include them in the following chapter.

6.5.2. Nano-RUF Business Plan Draft

- **Company Nano-RUF (Rapid Urban Flexible)**

Vision: Personal, sustainable and balanced mobility for the 21st century. Drive Nano-RUF.

Mission: The Nano-RUF enables and establishes an innovative personal mobility concept. It offers an efficient, green and convenient transportation directly from A to B.

Values: From sustainability, reliability and safety to efficiency and profitability.

- **Executive summary**

In our society today, most people want to be able to drive individually and without long planning or waiting time from origin A to destination B. Therefore, new personal mobility concepts have to be developed to match these needs. Due to the Urbanisation the cities are growing, the normal travel distances for example for commuting are often more than 10 kilometres. For metropolitan areas like Copenhagen the Nano-RUF system together with the other RUF vehicles would improve the overloaded traffic situation. The aim must be to clearly show the benefits of the Nano-RUF, as an environmentally friendly, very comfortable, trendy and altogether economically good transportation system. As the batteries do not need to be as big as in conventional electric cars and the batteries are charged on the monorail, this eases the implementation. Because the main problems with electric cars are the battery sizes and the charging process. The Nano-RUF has a compact lightweight chassis, is easy to fit in any parking space and very aesthetically pleasing.

- **Product and service**

The Nano-RUF is a one-seater electric based vehicle that is able to drive on the RUF monorail for longer distances and on the normal road for short distances to get to the RUF monorail network. RUF is the acronym of Rapid Urban Flexible and Nano stands for the smallest vehicle of all the RUF vehicles. The Nano-RUF system is able to reduce the traffic problems in the cities and be a more sustainable transportation system. With RUF system being patented and good branding the system can prevent others from copying the idea.

The great advantage is to be able to move individually from home to the destination within cities and combine this free choice with the advantage of using the train system and therefore increase the efficiency of the system.

For the customer the system can offer several advantages. On the monorail the driver can relax due to the automotive drive system, and therefore is extremely safe. It is a very time efficient and comfortable transportation system with the possibility to get in at home and get out at the destination without the need to change. The costs will also become competitive due to the rising oil price. The Nano-RUF offers nearly no stopping en route, just slows it speed at the junctions. The customers at most have to wait a short time to be connected to the monorail. The customer has the freedom to travel at any time and also has a high level of privacy and comfort. So the customer can hear the music of his own choice and is not disturbed by other passengers. The monorail secures more predictable travel time. Congestions, accident risks and noise level due to the smooth monorail ride are reduced. The group has not looked into the concrete production or manufacturing plan of the Nano-RUF. But one scenario is that the car manufacturers will produce the Nano-RUFs and the other RUF vehicles, so they can use their expertise in this field.

- **Market and customer**

It has to be differentiated between business customers who build, buy or own the monorail infrastructure and operate the system and the private customer who drive and buy the Nano-RUFs. The first ones could be all kind of investors. Recently government investors have shown interest; one in Sweden and one in India (Jensen 2008). Their interest is to create a better transport infrastructure, adapt their systems to the needs of this century and create a more environmentally friendly and economically justifiable system.

The final customers could be all persons allowed to drive. At first one could think that there is a very limited market for a one seated vehicle like the Nano-RUF. But although even for families it could be a useful additional vehicle, for example to commute to work. As the group made a survey and a questionnaire, it shows that nearly 75% of all people are driving alone. By nature the one-seater is very attractive for singles, new drivers and elderly people living alone.

In the beginning most Nano-RUF drivers are likely to be between 20-50. Because they normally do not have a strong brand loyalties like older people. This matches with the marketing side because they can be longer customers and maybe recommend and buy it for their children when they become adults.

A typical customer can be either single, earning good money so that he can afford to spend on a trendy, convenient and green Nano-RUF, which could become a kind of status symbol, or as one of two vehicles for a family. Because most likely both parents want to have a vehicle. One bigger vehicle like a normal RUF to drive the children, to use it for family getaways, and another Nano-RUF to commute or driving alone. Therefore, the Nano-RUF should have some individual flexible components like the car colour that fulfils the trendy claim.

The possible market size in total is very large, because the Nano-RUF is attractive for all people that are using a transportation system for more than short distances. There is no need at this stage for a detailed consideration of the exact market size. The priority is to get the system started. Later on this might be examined in more detailed, if precise information is necessary for gaining production numbers etc.

- **Industry and Competition**

There are mainly three parties. One is the car manufacturers, one the train companies, and the third small companies with alternative transport solutions.

There are some other companies searching on dual mode concepts: TriTrack, Pullaway, Dual Mode Vehicle DMV and MonoMobile. But now, the different dual mode companies do not act like rivals, it would probably help RUF if any other Dual-Mode-Concept is implemented. And the RUF technology is patented (Appendix 2).

If the RUF monorail infrastructure works, the car manufacturer could become partners and design and build Nano-RUFs as well. Because they can use a lot of their knowledge and adjust it to the Nano-RUF specific elements.

At this stage of the Nano-RUF, the RUF Company should focus to convince public institutions and organisations, because they spend a lot of money in the transportation infrastructure. If the Nano-RUF could be implemented on a long test track or a small real track, that would help a lot to get other partners and investors on board.

- **People and Organisation**

RUF international is owned 100% by Palle R. Jensen, the inventor of RUF. Palle R. Jensen is a member of the Danish Society for Creativity and Innovation. As passion is one of the most frequently observed phenomena of the entrepreneurial process, it is critical for entrepreneurs to convince the targeted individuals to invest their money in the new venture. Those entrepreneurs, who have accurate and detailed knowledge about their proposals, have the advantage according to an academic study [Chen et al. 2009]. Mister Jensen has shown this passion for the last two decades.

He received different funding in the early stages from the Copenhagen Traffic Authorities, the Laboratory for Road Data, Ministry for the Environment and also a grant from the COWI foundation. A consortium was formed in 1993. Mogens Balslev A/S Consulting Engineers was the main partner for a long time of period during the '90s, but they forced to withdraw due to bad economy so from 2004 RUF International is 100% owned by Palle R. Jensen. Nowadays the Lounsbery Foundation is supporting the creation of RUF no. 2. The inventor was also invited to participate in two research consortia funded by the EU – CyberCars and CyberMove. RUF no. 1 was built and successfully tested in 2000. There was a 1:1 design model as well as a test track next to the Copenhagen University College of Engineering. The proof of concept test was performed successfully. In 2011 there will be another project about building RUF no. 2.

The inventor has connections to a lot of experts from all over the world in the expertise of alternative transport solutions, for example with the Texas A&M University institute CEETI (Centre for Energy, Environment and Transport Innovation) as well as the Institute for Sustainable Transportation in Sweden. There has been a global media interest – from CNN, BBC world to European TV stations, i.e. German, Belgium, Dutch, etc. RUF has also been presented at several international conferences.

- **Money and Feasibility**

As the RUF Company needs money to build the monorail, it is searching for an investor. There are several possibilities.

First of all, funding from public services or subsidies from the government is one possibility. They spend a lot of money in transportation infrastructure and the aim must be to convince them to invest also into the promising RUF technology. Other possibilities are funds from private individual investors, from an angel investor, a venture capital fund or a donation/foundation. Crowd funding is an interesting concept, too. This is a concept where private people pool their money together and support efforts initiated by other people or organizations. Nano-RUF could create a good informative webpage and try to convince people via the Internet. When a lot of people are involved, even a small investment can become a successful funding. There are web pages like IndieGoGo or several others [Prentice 2011] , which hosts funding campaigns. Since the U.S. President Obama used crowd funding successfully during his election campaign and now tries to boost small-business growth with this instrument, it is very popular in the U.S. As an example, IndieGoGo has as of April 2011, 24000 projects seeking funds on its site, spanning more than 150 countries [Loten 2011].

There are several possibilities of including the crowd. It can just be that the crowd funds the project, but it could also be that the crowd advise the entrepreneur and promote the project via online social networks, or that it gets voting rights for decisions. The group thinks that the RUF company should try to get crowd funding for the Nano-RUF as well as try to convince other investors, but try to avoid giving too much right to say to the crowd and also investors.

To implement the Nano-RUF possibilities like building a small-scale system or another test track at airports, large amusement parks or other similar options should be considered and pointed out to the government or an investor.

With the implementation of the first real line, the company plans to demand a license fee. For a customer in India it was negotiated a license fee of 1% of the project sum for 30 years for all RUF projects in India, in total 120 million EURO. This kind of model can be used for all countries. Even if in the beginning the company needs some additional funding from the public, this is justified by the benefits of the system and should payback financially for the government due to less congestion, less accidents, etc.

- **Implementation**

There are some milestones on the way to implement the Nano-RUF. First of all, the technical solution needs further work. Some problems have to be solved as well as some parts have to be considered more precisely. The search for an investor should be intensified and done more systematically. A big marketing campaign for the private customers is not necessary, because the monorail infrastructure is needed and if this is done there will be automatically some press. Besides the RUF system has appeared several times in the media, so the brand awareness is not the problem.

6.5.3. Summary

In the group's opinion, a Business Plan could help the Nano-RUF implementation as it enables it to get funding. Even if the main focus of the project was put on the technical specification, the demand and the description of the Nano-RUF was also an important task, which includes the main business aspects. As a detailed marketing plan is not useful at this stage, the group decided to concentrate on the Business Plan. It is a useful tool to show the technology to all kinds of potential investors and as well a systematic way to describe the Nano-RUF.

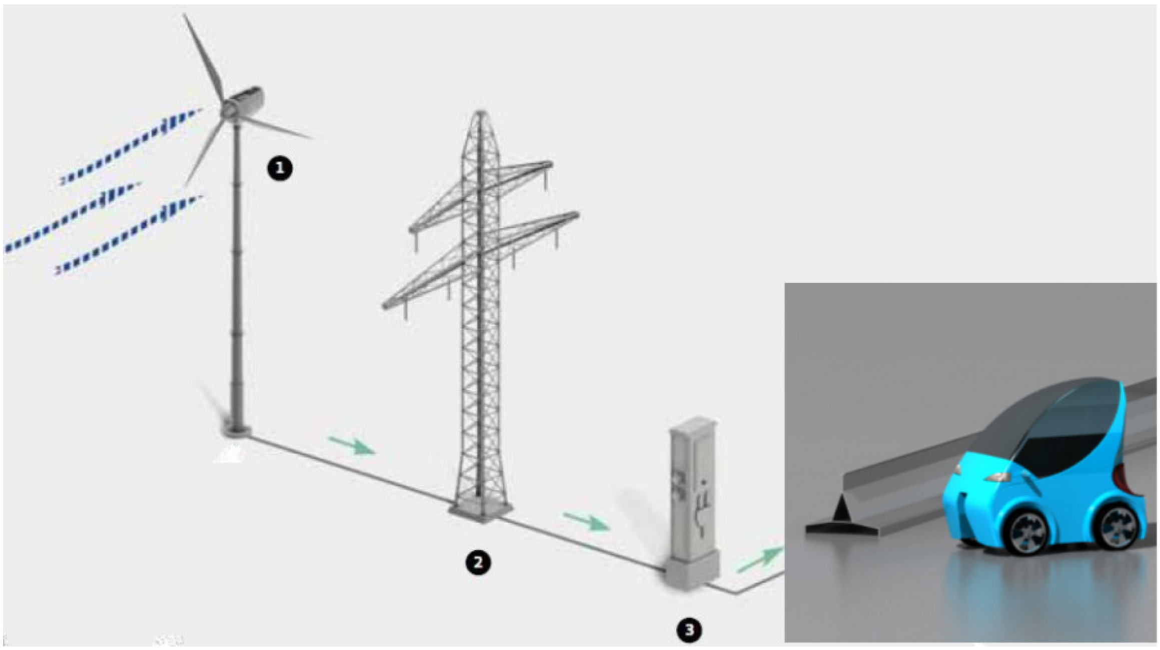


Figure 6.9: Sustainable Nano-RUF (Source: Adapted from: [Melfi 2011])

The Nano-RUF can lead the way to a sustainable, balanced mobility. If renewable energies are used to produce the electricity, this is a zero emission transportation system.

7. Concept Design

This section explains the idea generation process through concept sketches. It shows progression from early work to a clearer more defined product for the Nano-RUF range. It was necessary to start concept work before the final specification was complete to visualise different angles of approach. For example the number, size of the wheels and doors. Different designs were formed and analysed by the whole group to assure the best possible solution was accepted for the problem. It was necessary to follow the specification and the design brief when creating new design work to ensure the product was right for the target market. See Appendix 8 for complete design works.

7.1. Preliminary Considerations and Overall Layout

7.1.1. Introduction

The group spent a great deal of time considering the different options on how to design the vehicle. From the layout of the components inside the cabin, to concerning the dynamic aspects. They all have been integrated in the most space efficient, simple and lightweight package. Making all of the elements work together was a very tough task to perform as well as time consuming.

The monorail system requires a design where a hollow beam runs directly through the length of the body. The lack of an internal combustion engine is also very important for this particular body construction. These two details completely change the design, which in the case of a normal car is based around the engine. A cost-reducing element is that, thanks to its single seat layout, it is a symmetrical car, without the need to produce different models for either left or right hand drive countries.

7.1.2. Initial Concept - Segway Based Design

The first option the group had to look at was the initial concept proposed by the project supervisor. It consisted of a Segway based system that would be able to adapt to the dual system for use on the rail and on the road. It was to be encased in a fully closed cabin, around a standing person which gave it the appearance similar to an English phone booth on wheels. This was considered a very unattractive design.

Figure 7.1: Segway (Source: http://www.segway.es/i2.asp)

This idea has some interesting advantages such as a very compact design due to the standing position of the user and the ability to park the Nano-RUF in less than 1 m^2. Before any previous research was to be completed an advantage was the use of the existing technology and its simplicity.

Some car manufacturers have already been studying the Segway as a mobility alternative, such as concepts like the Puma. This was based on the idea of having a two-seater Segway. It proved to be too compromised, as it required additional wheels for balance while stationary. The design did not comply with safety regulations.

This evidence gave the team an idea on some of the shortcomings of the Segway concept development for other uses or purposes.

A more comprehensive study revealed the need of relocating the inner components of the Segway design in order to give way to the rail beam could prove problematic. As can be seen in Figure 7.2, the main components are located centrally, the position which has to be hollow due to the monorail requirements.

Figure 7.2: Segway System (Source: www.tusegway.com)

More importantly the patent system of Segway and the cost of manufacturing it would prove too high compared to other alternatives that the team looked into. Other issues were the standing position, which could become tiring for the user.

The next step was to try to develop a similar solution from more economical components. Several meetings and careful individual thought from each member took the team in the direction of a different approach for the vehicle. A two-wheeled vehicle is simpler and more compact than a four-wheeled vehicle, but highly unstable. The solution adapted by Puma with its auxiliary wheels is compromised because the integration of these elements is not safe for pedestrians and requires space within the design. Higher cost is caused by the design and manufacture complexity only to achieve stability when stationary.

Figure 7.3: Puma personal mobility concept (Source: http://pixel-shack.net/tag/segway/)

Further discussion took the group in many different directions, such as a three-wheeled vehicle that does not have a central beam design (use of a platform or an open train wagon for commuting in the rail system), and several four-wheel options, some had four wheel steering and even rear wheel steering.

Eventually, all of those options were discarded either for their production complexity or their cost. The three-wheel system requires a design, which does not carry a central beam along the length of the vehicle in order to locate the wheel in the centre of the front or the rear. A four steering system is both costly to design and manufacture, without any relevant advantages that justifies these efforts. A rear steered vehicle is counterintuitive in the current background and could prove far too problematic for the user to accept such a system. The time to develop this concept is very limited but it is necessary to have a solid base so that the following groups can develop the Nano-RUF from a proper starting point.

After several options were contemplated for integrating the rail system with other than four wheels, it was accepted that this was the most suitable option. An initial reluctance to use this conventional layout was present in some members that thought this characteristic would not help to distinguish the vehicle from a regular car.

7.1.3. Passenger Layout

Part of the team thought that it would not be unreasonable to be able to carry an additional child size passenger, mainly for the purpose of using the Nano-RUF for the school-run, which is usually at the same time as the rush hour.

The option most likely would consist on using the luggage compartment behind the driver's seat and turn it into an occasional second passenger seat.

The estimation of the size required to fit another passenger was the main disadvantage in such a critical parameter as space is in this project. Backed with some surveys carried out by team members showing that at rush hour close to the 75% of users travel alone. It was decided to have the vehicle as a single-seater.

7.1.4. The RUF-McPherson Combo

After accepting the four-wheeled option the team considered the existing projects for the RUF system to be a good starting point. Research was done on the layout of the elements in the vehicles and it was found to be composed of a very complex tubular frame in which a dual drive train system powered by electrical motors was secured to the monorail by a clamping device.

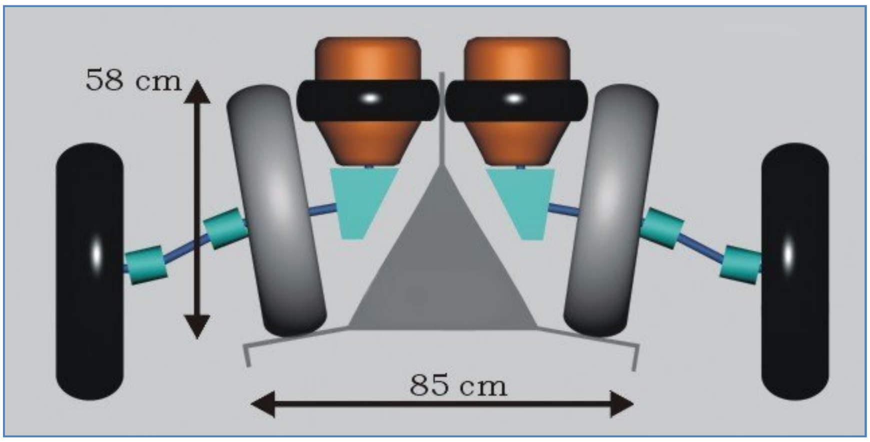


Figure 7.4: RUF System on the monorail being propelled by the clamping tyres (Source: http://www.ruf.dk/files/index.htm)

On the road it is meant to be used as a normal drive system, with the added advantage that once it gets to the monorail system, the “clamping tyres”, which are positioned parallel to the ground are pushed together against the monorail to secure the vehicle and prevent it from being derailed. The drive train switches the power to the low friction tyres specifically designed for this purpose, so that energy consumption should be more efficient. While at the same time the vehicle is automatically guided to the user’s preferred destination and controlled by a computer navigation system.

The complexity within this design makes it a very hard task to design a compact suspension, steering and drive train chassis that can be compatible with the dual-system. Although the monorail system promises reduced friction and consumption, it is still a big issue to use twice the amount of tyres and constant velocity joints per corner. This also means adding weight, higher inertias and complexity to the non-suspended elements of the suspension as well. It is very inefficient and costly.

For the road system the construction is based on the McPherson strut which is the most space efficient suspension system. This is due to integrating the coil and the damper in a common strut that starts in the hub and ends above the tyre by bolting it to the body. Previous work by other students used this design as a starting point. It certainly is a very compact system for common automobile designs. This design adapted to the Nano-RUFs is a very complex, heavy and bulky set up.

For the monorail the drive train switches the power to the monorail wheels and the clamping wheels secure the vehicle to the rail. The monorail tyres are efficient and produce low friction, which should help to reduce energy consumption drastically. The clamping wheels can only add drag, so a more suitable solution to this is to be found if the team really wants to optimize the initial design.

Unfortunately the RUF dual system is far from being suited to the Nano-RUF design. This was not perceived as such in the previous projects and, probably due to a lack of real alternatives, this solution was found. A new solution would have to be found if the specification of the Nano-RUF were to be followed.

7.1.5. In-Wheel Motors and the Final Solution

The constraints in size lead to research for an in-wheel motor system. This research gave several options to consider, as it would affect the hub, brake, steering and suspension design.

Finally, a concept design was found from the VDO Siemens but now owned by Continental which consists of a drive-by-wire integration of the in-wheel motor, the steering, braking and suspension systems.

These findings and their integration to the Nano-RUF are explained in the following sections of the report.

7.1.6. Door and Entry System

An issue to take into account in the design is how to enter the car. The first constraint for a comfortable entry is the fact that there is a beam of at least 0.6m. High along the cabin. This creates a big issue ergonomically, especially if we think of the usual way to get into a car from the side.

Side Door

The conventional side doors might be accepted as the common way of entering a car and have been developed for over a hundred years. However the target customer for this vehicle has to be as wide as possible, the design team cannot forget that in order to fit people that are not so agile, such as the elderly. A different approach to entering the vehicle is required, as the beam is a main part of the design and cannot be removed.

Another constraint for side doors is more efficient parking. The car needs a space on either side to get out of it, when parked facing the sidewalk so some consideration for a wider space will be needed.

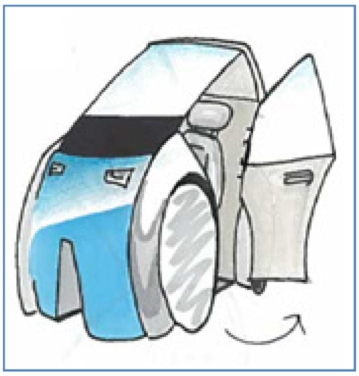


Figure 7.5: Side door

Sliding Door

An option to solve this later problem might be found in the sliding doors. Since they open in a more compact space they have been used and developed for decades. Some small cars already use this system for more efficient parking, such as the Peugeot 1007. The main disadvantage of these doors is the cost of development and production. Another disadvantage is the added weight to the car, the proven fact that unless these doors are electrically operated (adding cost and weight), they tend to lock very poorly. Lastly the need of rails on the rear fenders might compromise the design.

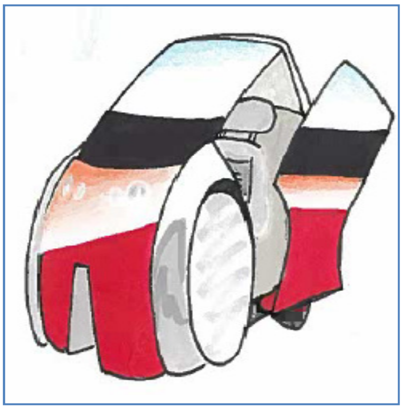


Figure 7.6: Sliding door

Gull Wing or Scissor Door

Another solution was the gull wing or scissor doors as seen in some sports and supercars. These were deemed unnecessary as well, as they did not provide any useful advantage over the other door systems. The purpose these serve is to reinforce the sills, which is not fulfilled since it is not required for the Nano-RUF.

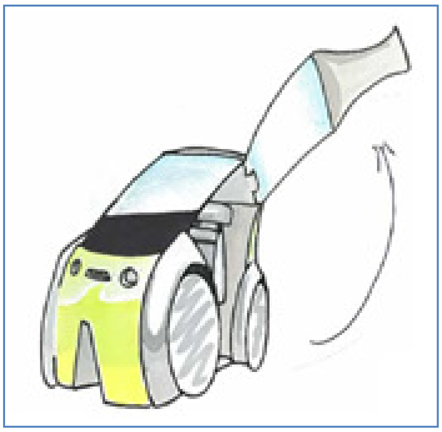


Figure 7.7: Gull wing door

Front Door

Fortunately, there was another possible option that would fulfil many of the mentioned ergonomic requirements whilst still being original and elegant. A front door is almost unheard of with few known successful examples, such as the Iso Isetta (better known as the BMW Isetta). See Figure 7.8.

Figure 7.8: BMW Isetta (Source: www.theblogofrecord.com)

Positive points for design are; the front door idea solves the very complicated task of entry without having non-agile people lift their legs over the monorail frame. To sit in the vehicle simply ease backwards into the seat. The user is already sitting in the car and it is even more comfortable to get in and out.

Another big advantage is when the car is facing the sidewalk when parked it is more comfortable to get out directly on to the pavement. It is also safer not having to deal with any of the traffic. It should be noted that no more paint scratching would happen with careless people opening the doors against other users' cars. Other pros are the simpler design and production cost of just one door on the front of the car, which also is easier for the technical components layout inside of the vehicle.

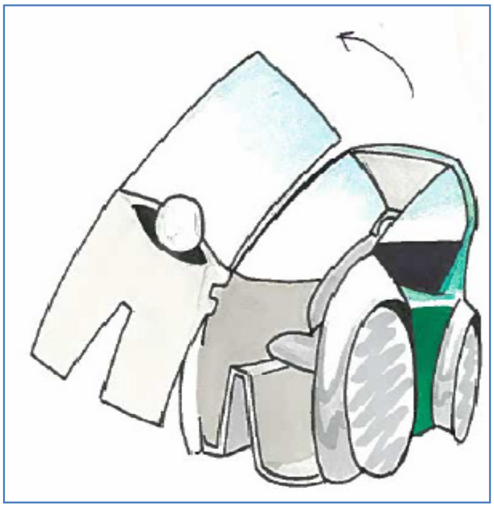


Figure 7.9: Front door

In order to give the vehicle its own personality, it was decided to use a vertically hinged door. With only one drawback being the clearance in low garages. Since any garage now a days can accommodate most of the big off-road vehicles this should not be a real problem. A solution at first could have been to hinge the door from its middle length and make it more compact but further discussions led to believe this may be even less space efficient, while more complex and costly in design and production, so it was discarded.

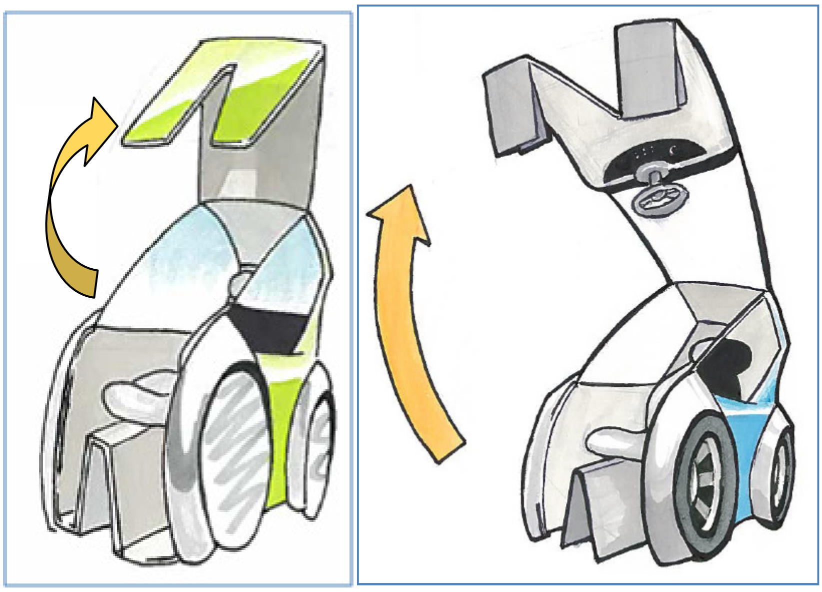


Figure 7.10: Front door

7.1.7. Conclusion

The requirements of this vehicle are very specific and unconventional, although the solutions adopted for it are simple and reasonable and allow the development of production costs to be as inexpensive as possible.

The vehicle is a single-seat body that has a monorail beam along the length of the car and is accessible to the interior via vertically hinged front door.

On the technical side, it is powered by electrical motors. Power is obtained from its limited range batteries or the energy provided from the monorail system. The braking and steering are also electrical drive-by-wire systems. They are all incorporated together with the suspension and the in-wheel motor system on the surroundings of the wheel and hub.

7.2. Cabin layout

The controls in the cabin are mainly distributed in two zones, the steering wheel and a HUD (Head Up Display) in front of the driver’s view.

Following is a description of the layout for the controls in the cabin.

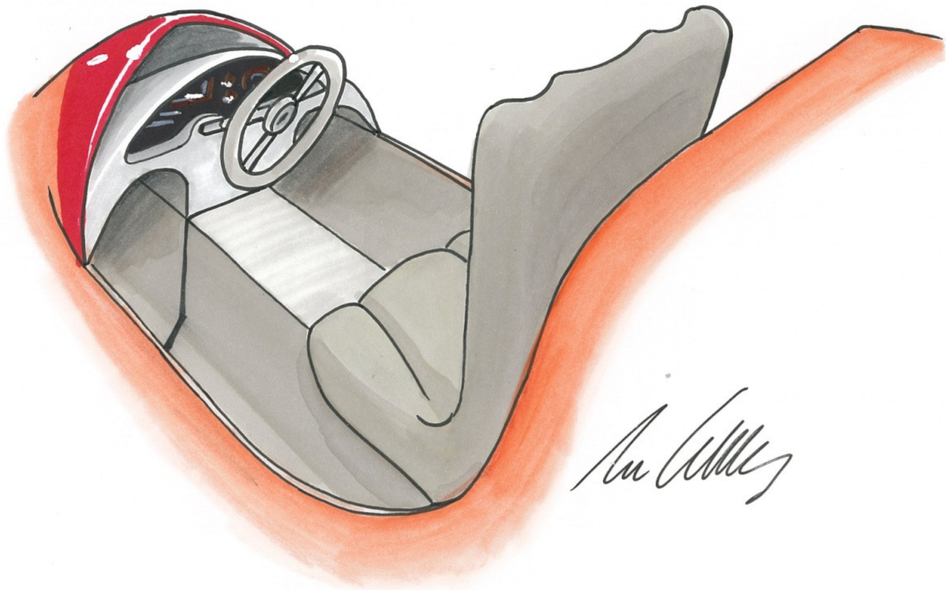


Figure 7.11: An early sketch of the cabin design.

Steering wheel

The steering will have comprised all of the buttons the user will need to operate the Nano-RUF. From simple buttons like the horn to the user options for setting the preferred radio station, mute the navigation system, etc.

The horn will be at the centre of the steering wheel, by pressing the RUF logo as in most road vehicles. This is done to make it easy to locate for any user.

Some buttons that will be in the steering will be for muting the radio, another for muting the navigation system's directions, two "half moon" touch pad scrolls that can be reached by simply stretching the thumbs, without moving the hands from the "ten past ten" position. One would be for volume control for the radio and another for the different radio stations or tracks available in the music format provided by the user (iPod connectivity, USB plug-in, etc).

Bluetooth could also be an interesting optional feature, so it would be necessary to have two buttons; one for receiving and another for hanging up or cancelling the call. A simple long press of the call button could activate a hands-free voice activated phone dialling.

Lights and indicators will be activated by a more mainstream switch located behind the steering wheel's left hand side, which will be more intuitive for users to use, especially if they need to flash the high beams momentarily. A steering mounted button arrangement could be unintuitive to flash the high beams or be confusing to use to some users, although some special cars have their indicators located in both extremes of the steering, like the Ferrari Enzo.

The wipers and water spray will be activated by another conventional switch behind the wheel's right hand side. For reasons similar to the light switch, a small squirt of water is more natural to be sprayed for the average user with this type of switch.

HUD

The Head up Display is a military developed technology that has been already used in the motoring industry successfully, pioneered by the Chevrolet Corvette. Some BMWs are starting to offer this technology in more mainstream vehicles (Figure 7.12).

Figure 7.12: BMW's HUD (Image source: http://paultan.org/2009/10/13/bmw-heads-up-display-now-in-full-color/)

The HUD will display to the driver all the information needed, from actual speed and estimated range, to the radio station and navigation system details from just a quick glimpse of the eye.

It will be projected in front of the driver's view, below the regular sight of the road, preventing it from distracting the driver.

If the user is being driven by the Nano-RUF on the monorail, the HUD can be used for other features as movie playing, TV, internet browsing, etc.

All of the design features explained in this chapter are shown as an example of the typical use of a Nano-RUF in the Appendix 5.

7.3. User-Centered Design

When designing the Nano-RUF it was essential that it fit and worked with the consumer perfectly. A detailed analysis of ergonomics and human form and how it could be used to benefit the Nano-RUF system was necessary.

From the start the Nano-RUF was designed for the target market. This was a vast category of ages and ethnicities; therefore a large variation of human shapes and sizes was to be considered. It was important that in the design process form followed function. This meant that the product had to function as it should before any aesthetic detail could be considered. The team took the approach of user centered design.

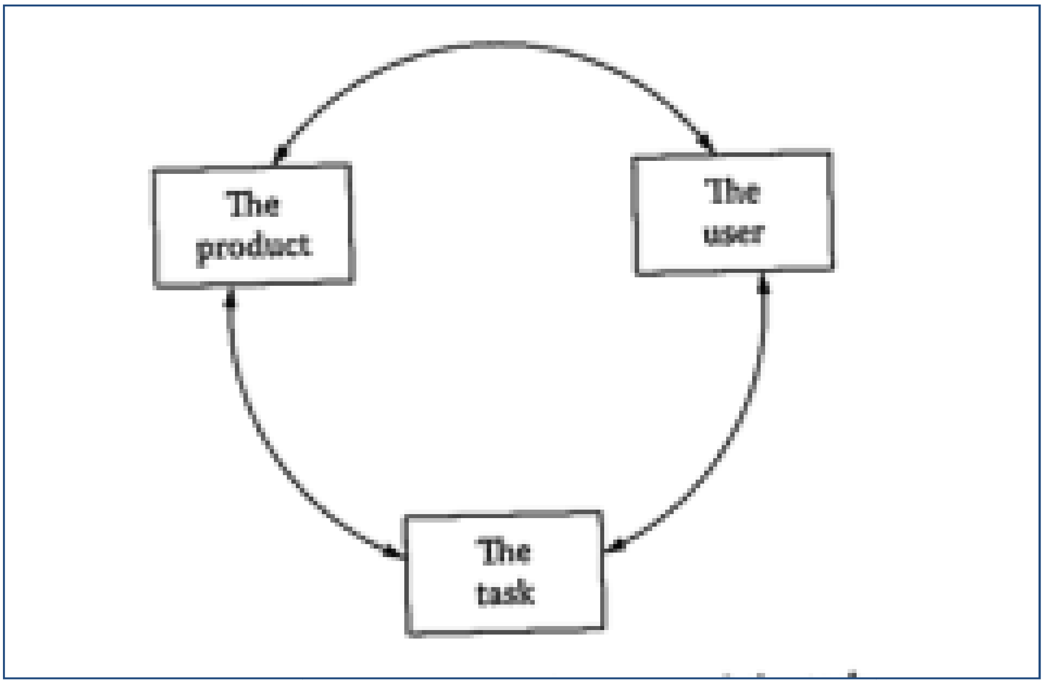


Figure 7.13: User-centered design: the product, the user and the task (Source: [Pheasant & Haslegave 2006])

- *User-centered design is empirical.*
- *User-centered design is iterative.*
- *User-centered design is participative.*
- *User-centered design is non-procrustean.*
- *User-centered design takes due account of human diversity.*
- *User-centered design takes due account of the user's task.*
- *User-centered design is systems orientated.*
- User-centered design is pragmatic. [Pheasant & Haslegave 2006]

User centered design is a cyclic process which involves the user in the research and the design phase. The method aims to fit the product to the user's requirements rather than making the user adapt to the vehicle, therefore creating the best possible match for the largest number of the population. It also considers social and cultural factors that might affect the task. User centered design focuses on how the consumer uses the product to complete a desired task. The designer looks at all aspects of the process when creating the product. Two methods in which this can be achieved are task analysis or a user trial. Since the Nano-RUF was still a concept a user trial was out of the question. Therefore task analysis was always in mind when designing the vehicle.

7.4. Task Analysis

To analyse the task for the Nano-RUF the designers had to put themselves into the users place and consider the cognitive and physical requirements. This lead to a breakdown of the major operations of the Nano-RUF. This included entering the vehicle, operating the vehicle and leaving the vehicle. A system was designed for entering and leaving the vehicle. See Chapter 7.1.6. The main consideration for this section was the user's affinity with the vehicle.

The first task was to design as many simple ideas as possible that met the requirements of the brief. Simple sketch work was created focussing on the compatibility of the RUF monorail system.

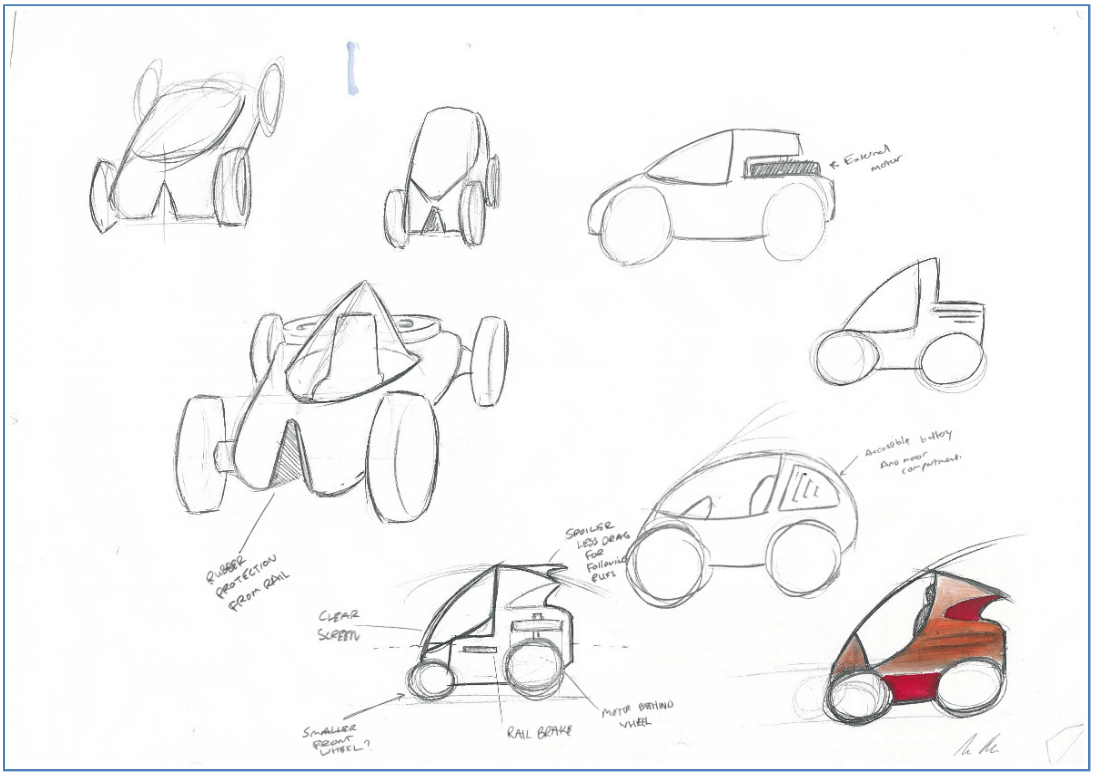


Figure 7.14: First sketch ideas

The first attempt at sketch work generated rough ideas about the shape of the vehicle and how the driver should be placed around the cockpit. The 'V-shaped' monorail system had to be taken into consideration as it runs directly through the vehicle. The sketches show that using four wheels for the Nano-RUF would provide more stability on the road and when used upon the monorail. A two-wheeled system similar to Segway would have been difficult to balance with the larger cockpit, especially against strong air resistance when travelling at high speeds on the monorail system. This meant that considering aerodynamics was a crucial component of the next design stage.

During the development of the Nano-RUF the mechanical aspects of the vehicle had to be considered as well as its visual properties. Components such as batteries, motors, suspension and steering had to be considered and fit within the design parameters. This was a tough challenge as the vehicle had to be as small and compact as possible. So more technical drawings and concepts were illustrated to create a better understanding of the space needed for the Nano-RUF.

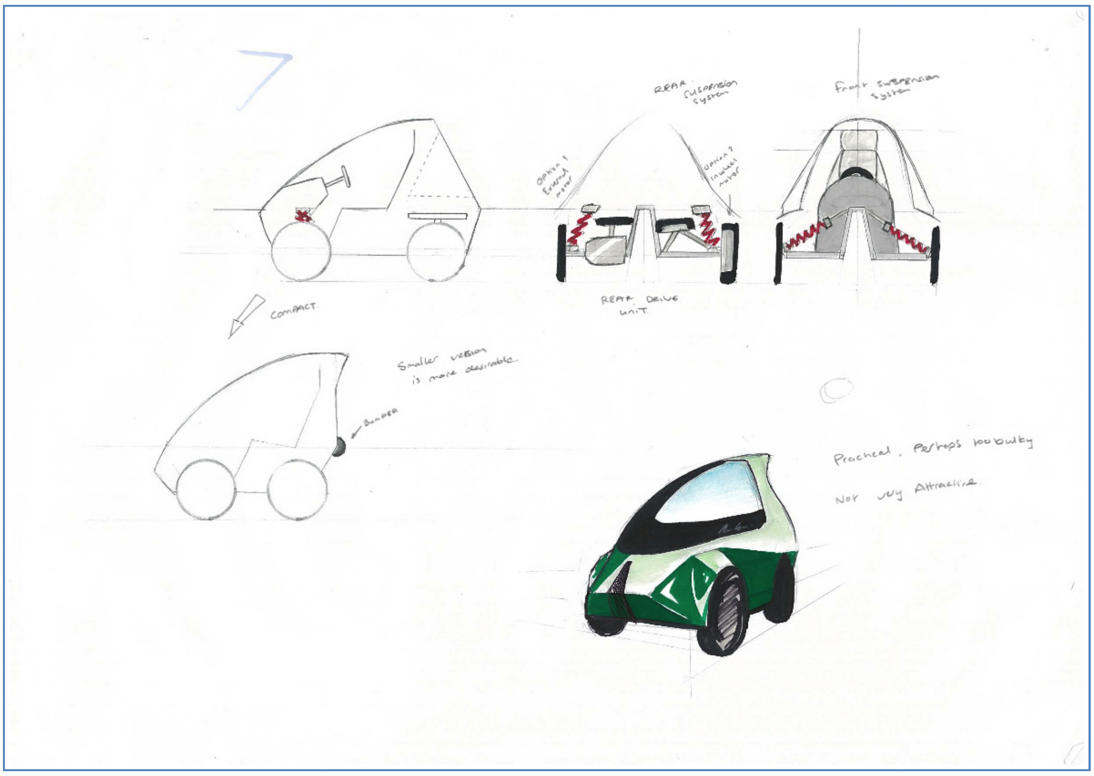


Figure 7.15: A concept focusing on the mechanical components rather than aesthetics

This concept consists of two motors located at the rear of the vehicle behind the driver. Each motor delivers power to the rear wheel. Once the vehicle is on the monorail system the power is diverted to the two horizontal drive wheels that pinch against the rail. The primary use of the front wheels is for steering. Suspension coils are fitted to each wheel and to the chassis of the vehicle to allow for a smooth ride. This concept was used as base for other concepts to be designed around

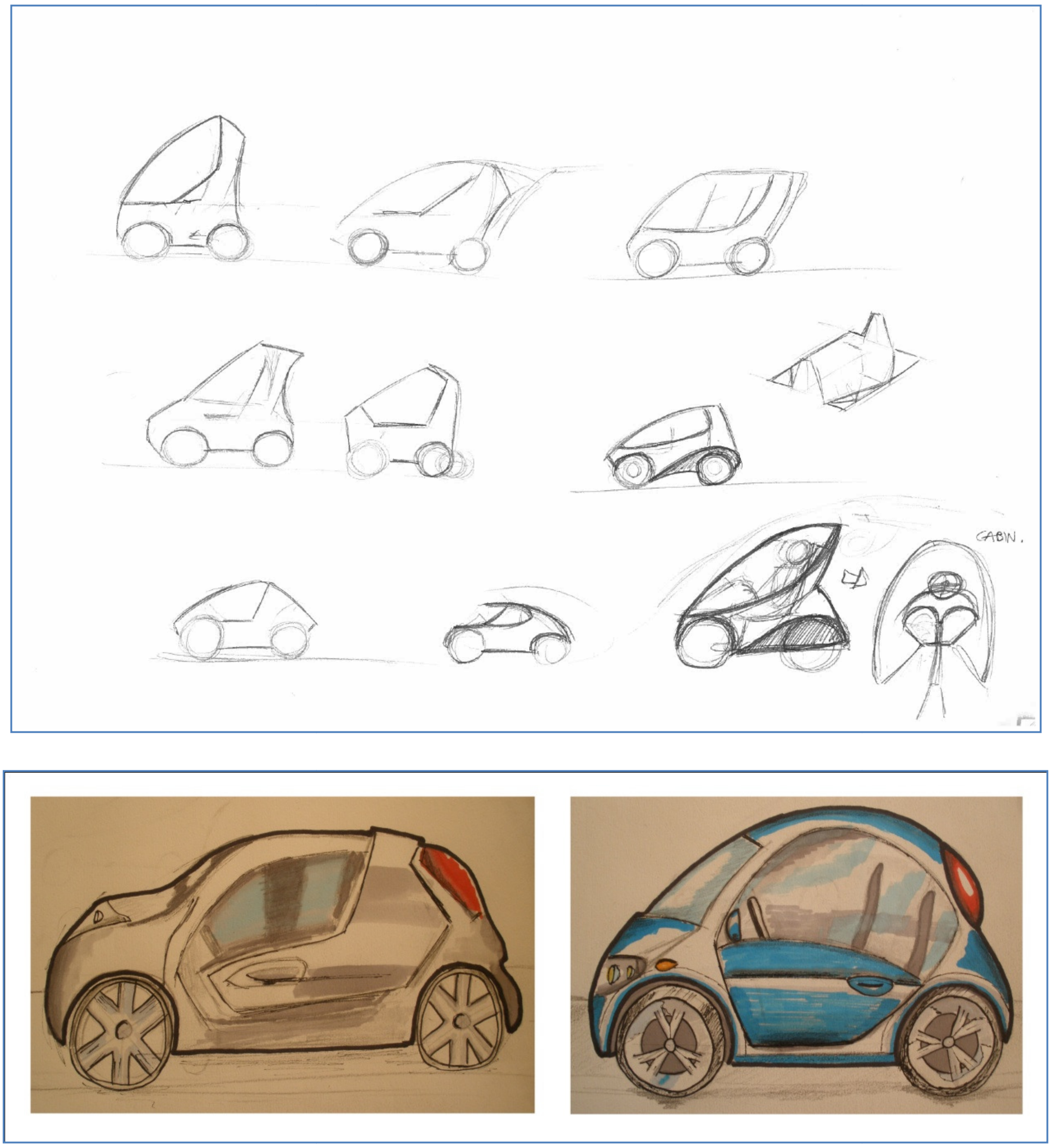


Figure 7.16: More linear designs considering the side profile of the Nano-RUF

As more concepts were created it was important to keep in mind the size of the product. It had to be as small and lightweight as possible to make it more energy efficient. This meant that the natural shape of the product was to be tall but thin. This was due to the position of the passenger being situated on top of the rail system. This is not a naturally aerodynamic shape as the full force of the air is hitting a large surface, rather than passing over a smoother flat gradient. (Figure 7.17). This had to be changed when the sketches were developed further. This didn't necessarily need a drastic re-design but meant that the specification had to be followed more closely. It was also plausible to consider the coupling system with other RUFs. A decision had to be made whether the Nano could link up with other RUF models to form a train. This was considered throughout the design phase.

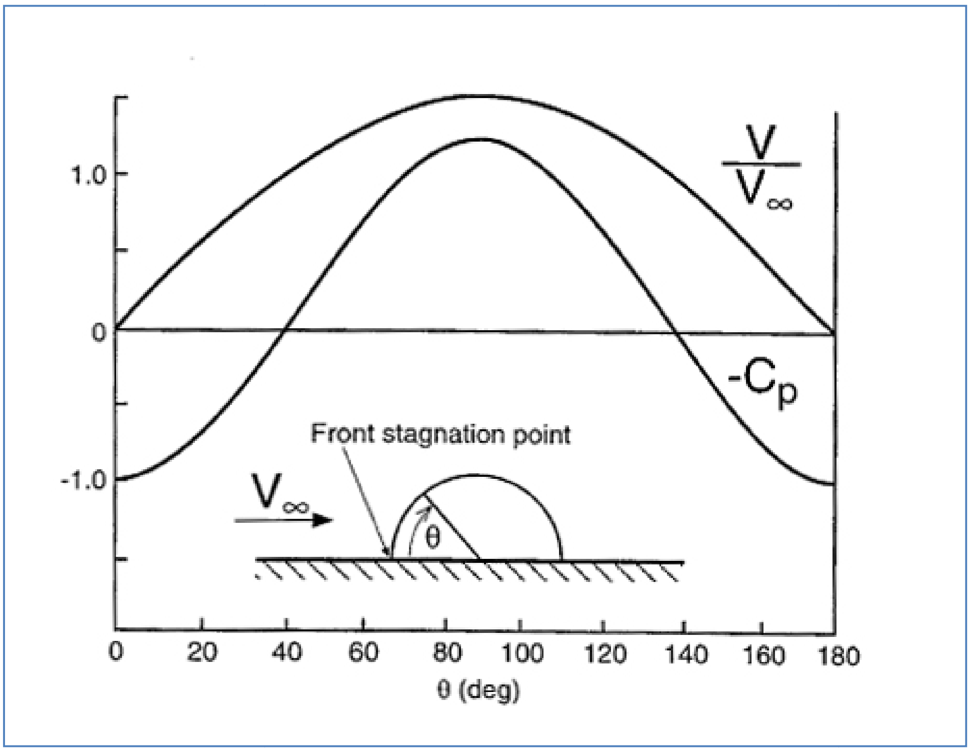


Figure 7.17: Shows the air pressure over a variable stagnation point (Source: [Katz 2003])

The above graph shows that a greater angle at the front stagnation point creates greater air pressure and therefore a larger drag force to slow the vehicle down. Taking this into account, designs were created with a lower stagnation angle and a more streamlined shape.

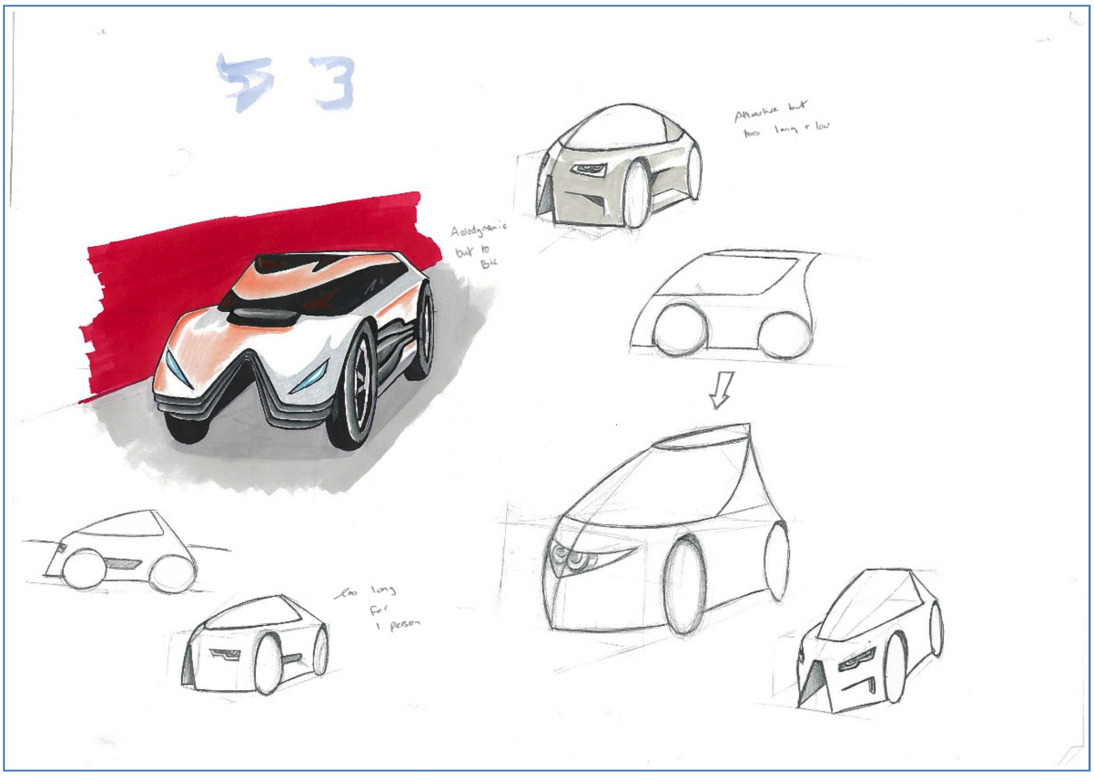


Figure 7.18: Designs focussing on aerodynamic shape

The above sketches were created to combat the aerodynamic problem that occurred in previous designs. These designs were more streamlined and looked more attractive but did not keep to the specification. The designs were too large and therefore too heavy for a one-person vehicle. This meant that these designs produced negative results but were an important part of the design process. They allowed the group to think critically about what was necessary and what was more important to the product. In this case energy efficiency is the main aim of the project.

They next stage of the design process was to create a set of designs that were small enough to be energy efficient and were streamlined to reduce the negative drag force acting against the vehicle.

Figure 7.19: New sketches combining aerodynamic shape with efficient size and weight

Figure 7.20: More examples exploring different wheel sizes

These smaller lightweight concepts were designed to be constructed from lightweight composites formed around a tubular structure. This would provide the highest strength to weight ratio and allow a variety of shapes. The designer also explored various wheel sizes. The rear wheels would be connected to the drive motor and the front, (smaller wheels) would be used just for steering. This would save weight for the vehicle. When this process was discussed in the group it was rejected for production reasons. It would be more costly to produce two wheels of different sizes than it would to create four wheels of the same size. Synergy had to be considered when developing the product. However these concepts started the idea of a ‘bubble’ cockpit. Meaning the top section of the vehicle was to be manufactured out of a clear composite allowing the driver to have a large panoramic view, which could potentially be more attractive and safer to drive. These particular designs fitted well with the specification but were not very attractive. The large windows were a concept that was to be taken further but to be developed into a more aesthetic product.

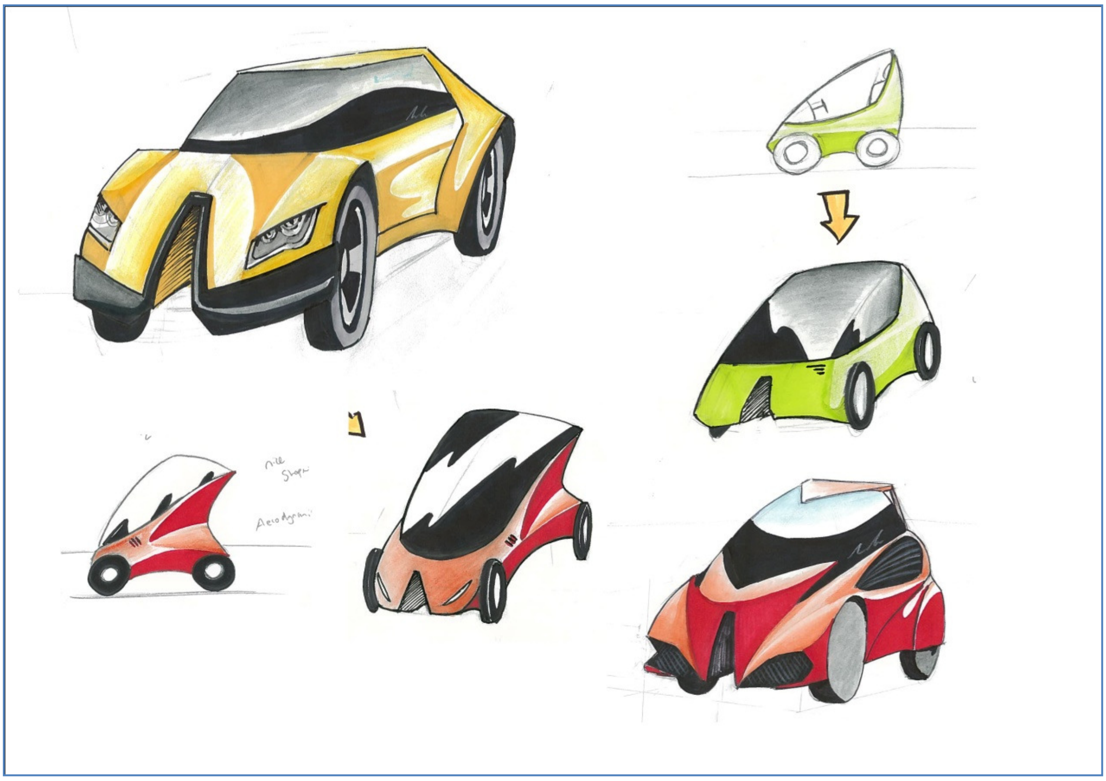


Figure 7.21: A development of concepts using the large windows with a more aesthetic sense

The next stage of sketch work was more elaborate with the aesthetics of the product. In some cases it worked well and in others the product became over complicated and just looked ugly. An important decision from this stage was to incorporate wheel arches into the design. The reasons for this decision were; Improved aerodynamic efficiency and enhanced aesthetic qualities. However the concepts shown above are too large and were beginning to look too much like a car. The designers wanted to create something that didn't look like a car because it would intrigue the consumer and make the purchase of the product more exciting. However the negative effect of this was discussed as consumers are used to the conventional car layout and may not accept the change. So the challenge was to find a mid-point between these two opposing ideas.

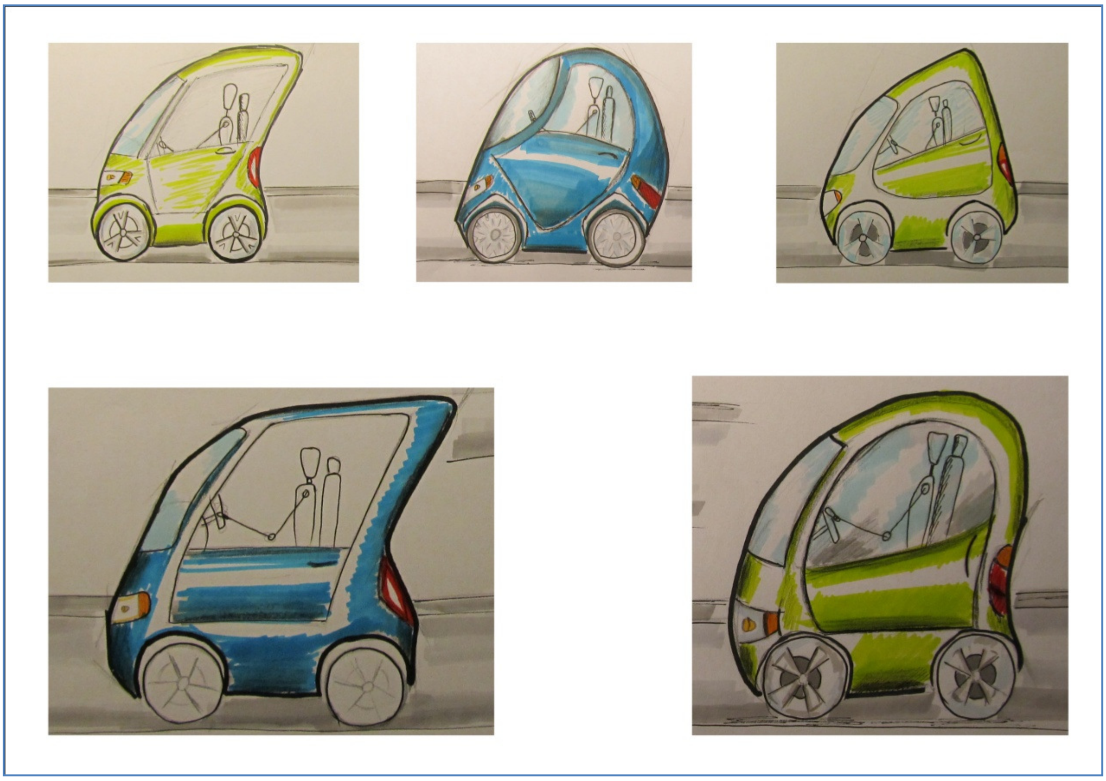


Figure 7.22: New compact concepts

The concepts shown above were used to explore the possible shapes and sizes that could be used. They are all compact to reduce space and weight of the vehicle. The designs also explore different varieties of door shapes. The most important factor from these concepts is the ability to connect them in a train format with as little space between each vehicle as possible. Notice the curvature on the front of the vehicle matches the curvature of the back. This reduces the amount of drag force when the vehicles are travelling on the monorail system. The arched back design allowed the vehicles to be coupled closely during bends and curves in the track. The mirrored gradient allowed rotation through the X and Y axis so the vehicles fit together well.

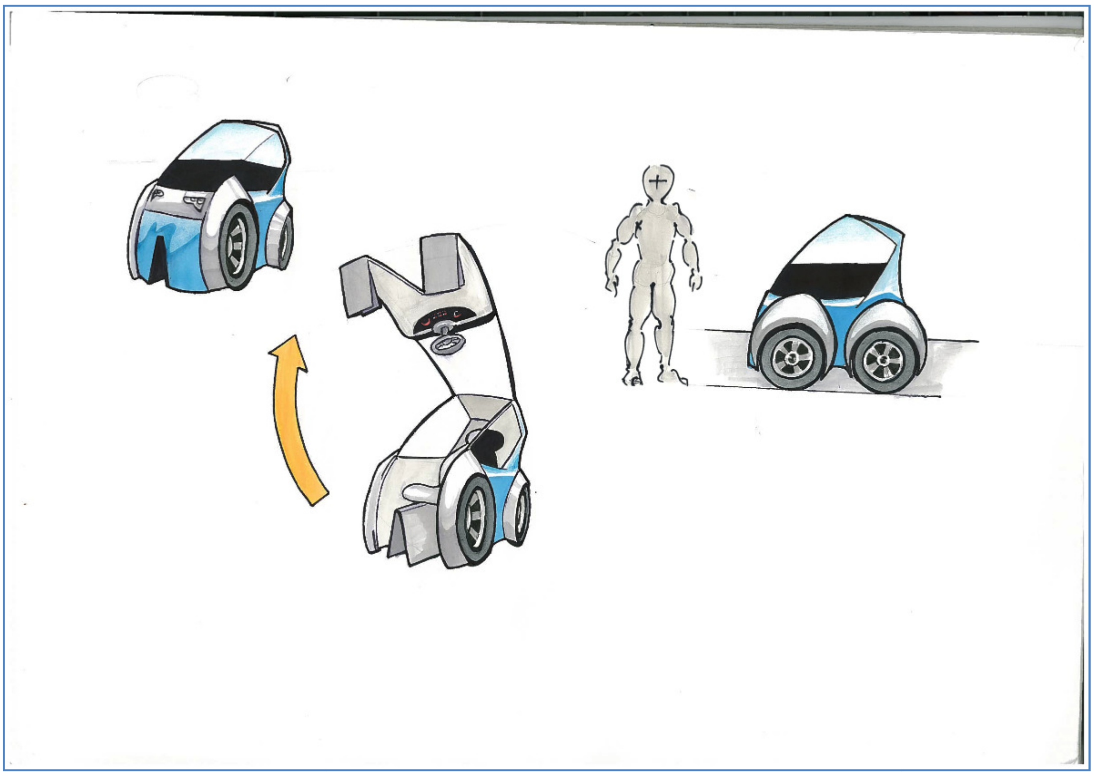


Figure 7.23: A compact concept using the in wheel motor system

As concept work was developed more and more research was completed by the group to explore modern drive systems and prototypes. One prototype was found that suited the Nano-RUF which utilized an in wheel motor, brake, steering and suspension system. (Chapter 7.1.5) This was better than the old two motor concept as it was much more compact and did not inhibit space within the cabin. This also produced a lot more freedom to design smaller more attractive looking vehicles. As most of the new components were electric it was much lighter and much more efficient. Because of the in-wheel motor system it was decided that large wheel arches were necessary to contain the various components. This also enhanced the attractiveness of the design and made it look sporty.

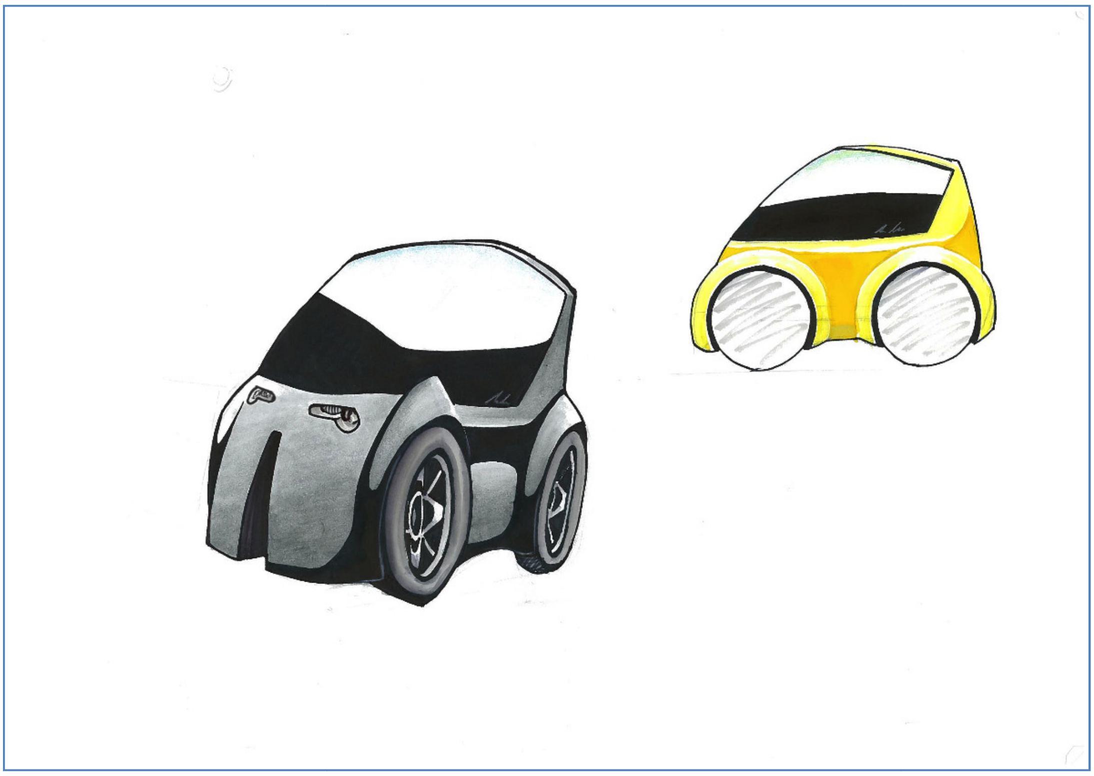


Figure 7.24: A new concept sketch utilizing the in wheel motor system

This design worked well because it was small, compact and lightweight, which meant it would use less energy to run.

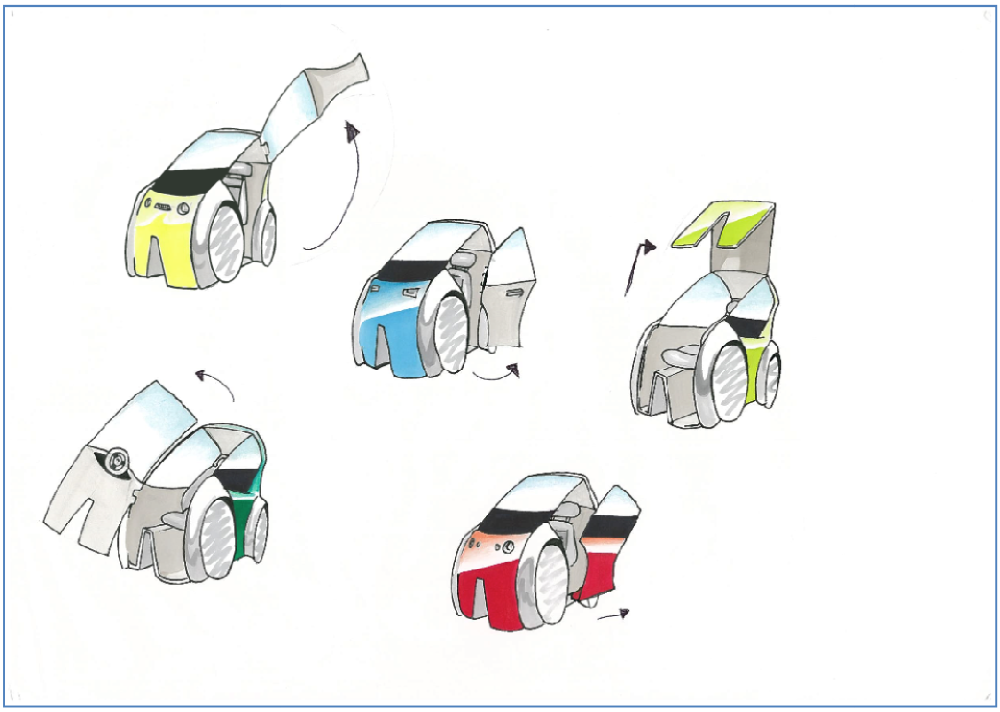


Figure 7.25: Illustrations exploring different door mechanisms

7.5. Anthropometric Design

In order to design the Nano-RUF certain parameters were required. It was necessary to create criteria that the vehicle should adhere to, to provide the optimum result. The user must feel comfortable in the vehicle for it to work efficiently and effectively. For the Nano-RUF four such parameters were used. The four cardinal constraints of anthropometrics: clearance, reach, posture and strength.

7.5.1. Clearance

Clearance is the space between the user and the environment of the product. In this case head space, elbow space and leg space. The vehicle had to provide enough space for the larger population to occupy whilst the smaller population still required a comfortable distance to reach the pedals and operate the vehicle efficiently.

7.5.2. Reach

Reach is the ability to operate controls comfortably. Similar to above, the operator must be able to reach the steering wheel and pedals without any visual obstruction from the dashboard or display. It was important not only to consider the maximum reach distances but the most comfortable reach distances for each percentile of the population.

7.5.3. Posture

Posture is the working position of the user in the environment. In the Nano-RUF's case the 95%ile and the 5%ile person had to occupy the vehicle in comfort. This was a two-way constraint, which may require some adjustability.

7.5.4. Strength

Strength concerns the application of force required to operate the controls of the vehicle. In the Nano-RUF strength is a one-way constraint, as only the minimum force is required to operate the controls.

Anthropometric data was gathered from external sources [Pheasant & Haslegave 2006]. This included body sizes for British adults aged 19 to 65 years. However it was not practical to take the mean values (50%ile) as it meant that 50% of the population would not be accounted for. So it was practical to take 95%ile male values and the 5%ile female values. This way 90% of the population would be accounted for and the target market would be satisfied.

7.5.5. Body Link Diagram

In order to satisfy the four cardinal constraints it was useful to plan out the body space of the user. A body link diagram was drawn using anthropometric data and Rebliffe's (1966) ranges of comfortable angles of joints. Data was taken for the 5%ile female (smallest) and the 95%ile male (largest). This meant that 90% of the population could be accommodated in the Nano-RUF vehicle.

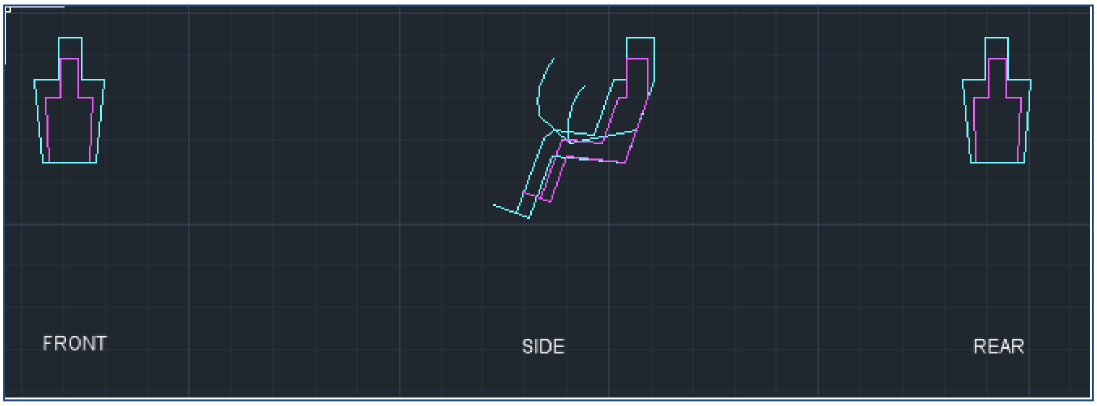


Figure 7.26 :Body link diagram for 95%ile ale (Blue) and 5%ile female (pink) used to analyse the drivers work position

The body link diagram also provided the necessary design constraints for the height, width and length of the Nano-RUF. This allowed the designers to gauge an accurate idea of the size and shape they could work with. In many occasions the body link diagram was used as a reference for design work and was later used to map out the correct dimensions of the RUF design, (See Chapter 8.6).

7.6. Further Concept Development

The following concepts were designed with the four cardinal constraints of anthropometrics in mind. This was achieved by using the body link diagram as a layout for the design. This provided anatomically correct sketches. Another major focus of the designs was to make them as aerodynamic as possible. Thus reducing the required energy to power the vehicle.

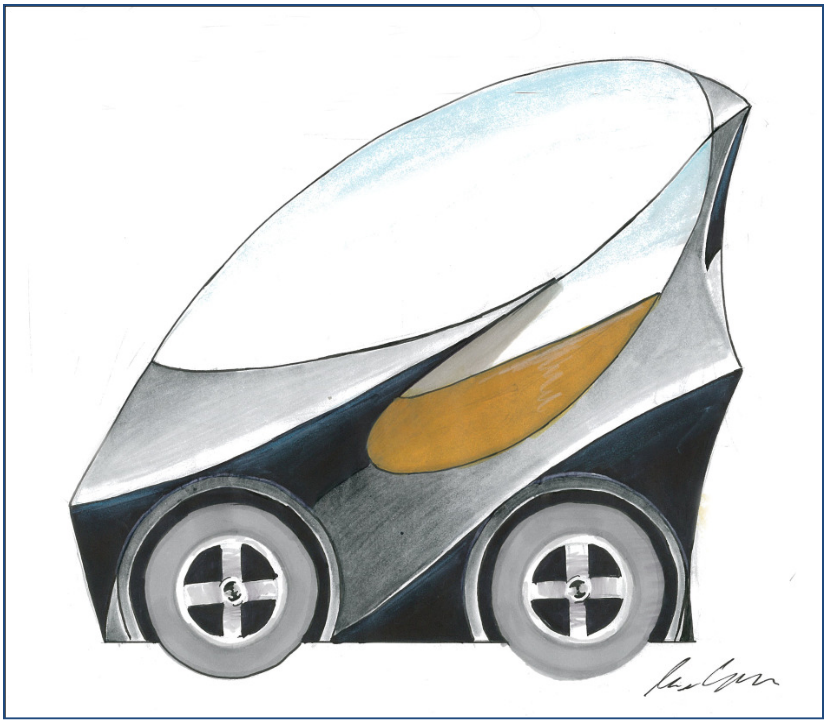


Figure 7.27: Aerodynamic concept

This concept was designed largely with aerodynamics in mind. The curves are designed to restrict air from moving under the car, instead forcing it up and over. The design however appeared too jagged and unapproachable to the user. This design incorporated a panel that could be fabricated from lightweight materials.

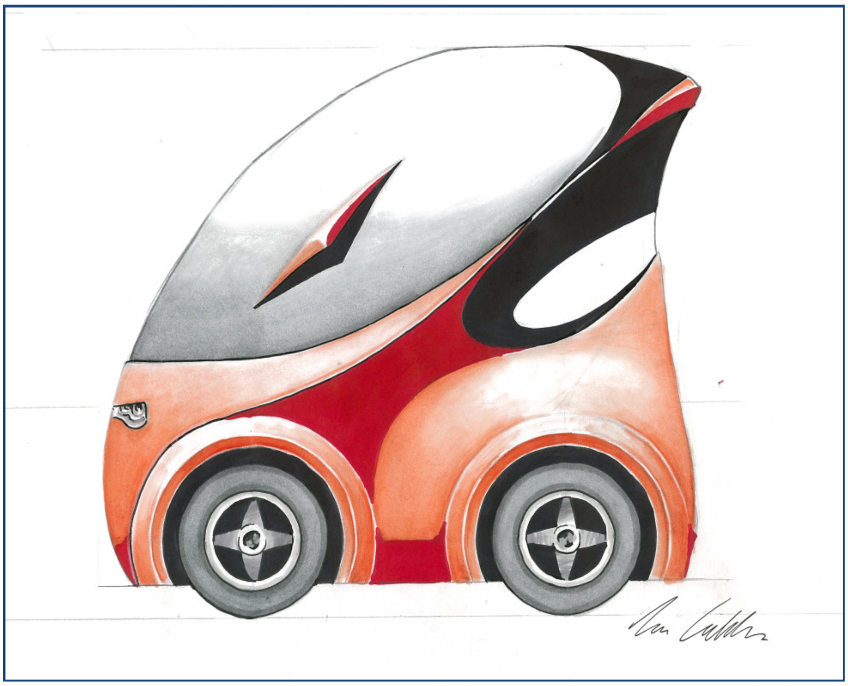


Figure 7.28: New concept for the Nano-RUF

The above concept was designed with airflow in mind. The air is supposed to flow up over the vehicle instead of acting as a negative force against it. Aerodynamic wing mirrors are introduced to this concept. The size of the wheel arches was increased from earlier concepts to make the vehicle look less tall and thin. This design incorporates built in strengthening sections to the cockpit window.

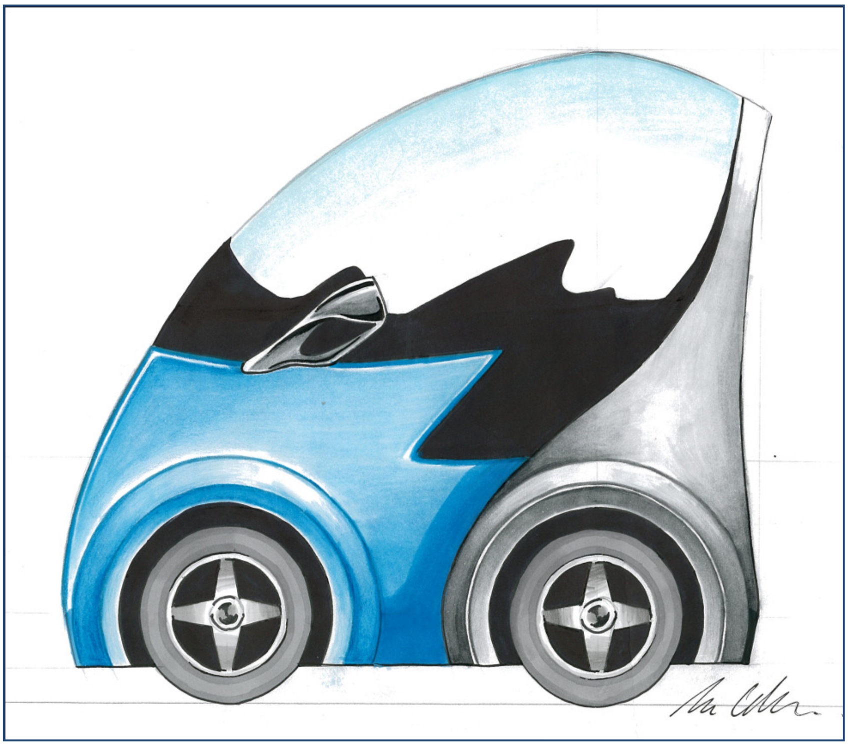


Figure 7.29: Two-part construction concept

This concept uses a two-part construction design where the front and rear are separate materials. Although not as aerodynamic as other concepts it offers new exciting aesthetics and a wide choice of materials. A lightweight mirror design is suggested. The idea was to prevent air turbulence building up in front of the mirror area.

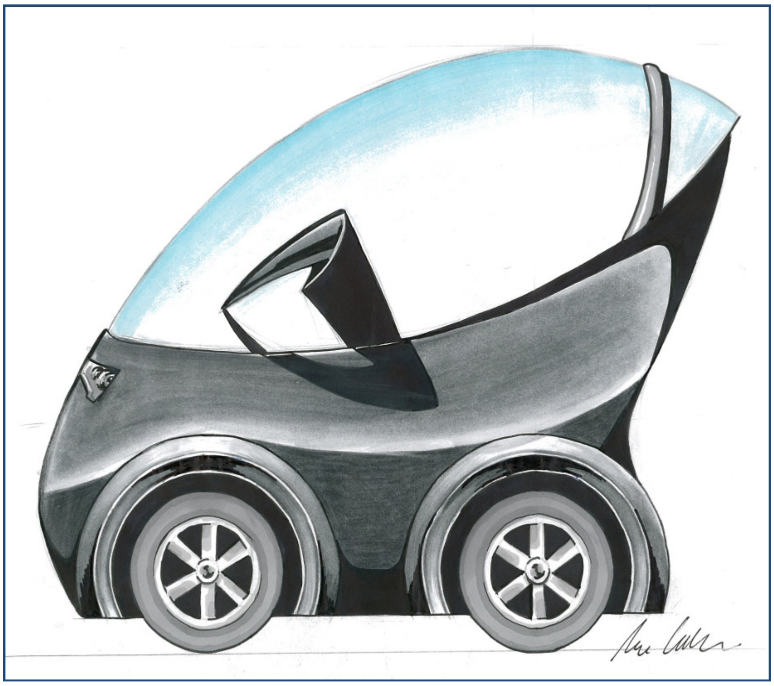


Figure 7.30: Smooth bubble concept

The ‘bubble’ concept was designed as a smooth shape where the cabin formed a bucket shape. A problem with this design was insufficient support for the roof structure of the vehicle. This could have been countered by a support beam, but it altered the flow of the design. Another concept for the wing mirrors was introduced.

Figure 7.31: An aesthetic variation

The concept above uses smooth curves to guide air to flow over the top of the vehicle. The group decided that the overall design was too flamboyant and a more subtle design was necessary.

However the group liked the aesthetic look of the rear section of the vehicle so it was taken further into another design.

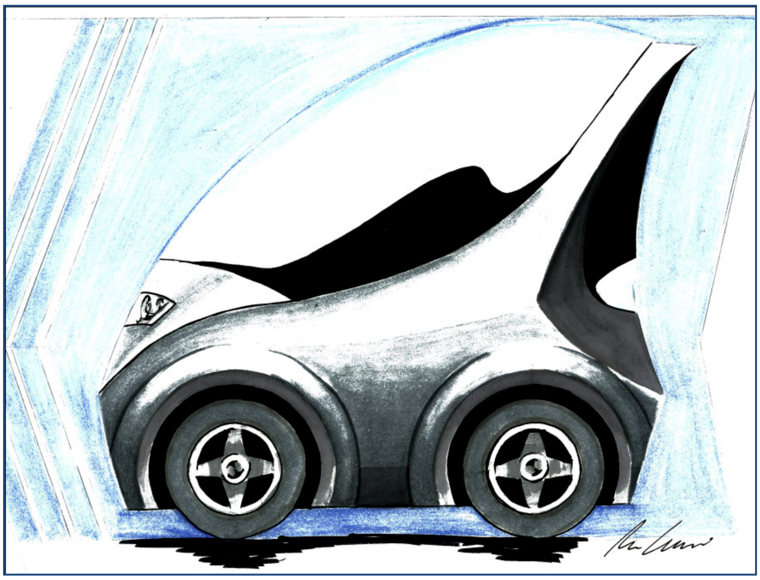


Figure 7.32: Chosen chassis concept

This concept was chosen for the final design of the Nano-RUF. It was composed of different attributes from other designs such as the large wheel arches, the flared back and the smooth aerodynamic curves.

7.7. Final Design

The final design is the end result of the concept design work. It comprises from aspects of different concept designs. For example the flared back detail was taken from Figure 7.31. The smooth curves serve an aerodynamic purpose. As the research described; a low angle at the front stagnation point reduces the amount of air friction. So the Nano-RUF has an acute angle towards the front of the vehicle that gradually becomes steeper towards the end of the vehicle. This allows air to flow up and over the vehicle and creating a downward force on the rear of the car. This down force creates a more stable vehicle.

The flared wheel arches serve two purposes. Primarily they conceal the In-wheel motor and suspension system and secondly they form an aesthetic illusion. The wide wheel arch gives the impression of a lower centre of gravity and a more sport-orientated vehicle. Even though it is not.

The window is constructed from a composite, which means it can be injection moulded as one large piece. This dome shape creates a more futuristic look for the vehicle and offers a new driving experience to the user. There is a large rear window to allow plenty of light into the cabin. Possible future work could be developing a finish to remove the suns glare. The task was difficult to make a tall thin car look attractive to the user. Especially when attractive traits of sports cars are low and wide. So the challenge was to make the vehicle appear wider without adding unnecessary weight or size. The final design considered 'Gestalts traits of attractiveness' to add further appeal to the user. The design achieves the target of looking like a new exciting vehicle without appearing to dissimilar from everyday cars. Thus allowing the user not to become estranged from the controls and function of the vehicle.

Figure 7.33: Side profile of final concept

Figure 7.34: A digital sketch of the final design

This image shows the vulcanized rubber bumper system. This rubber layer surrounds the section edge that integrates with the monorail. This is to prevent damage to the body section and helps to guide the vehicle on to the guide way of the monorail.

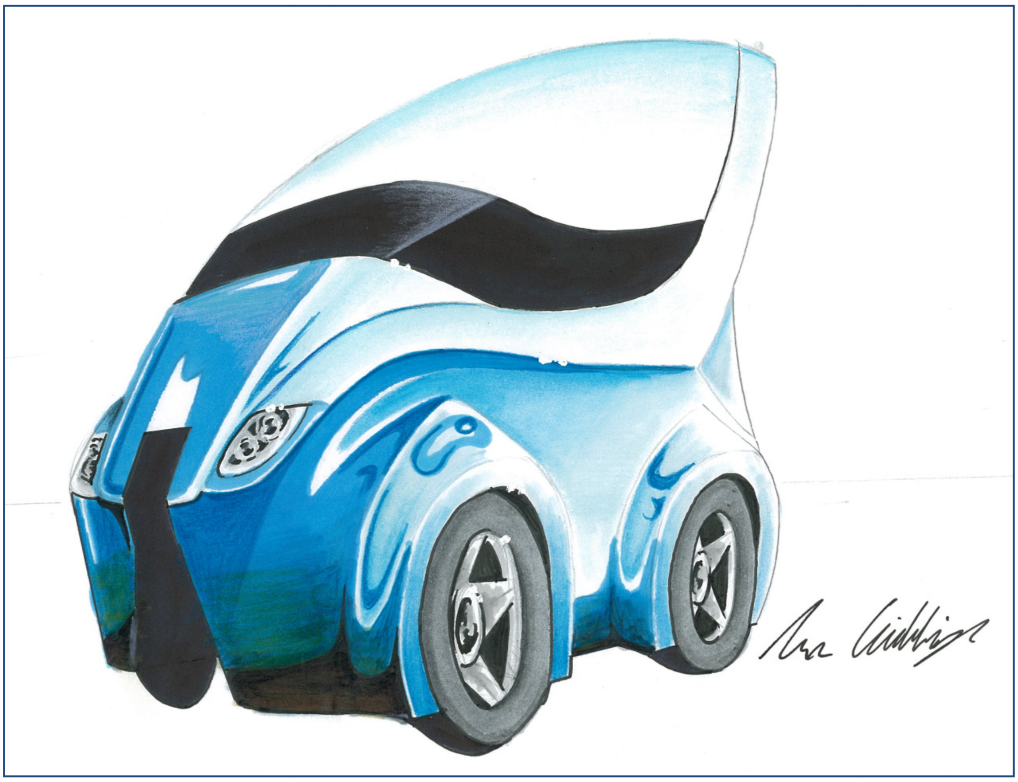


Figure 7.35: A pen render of the final design

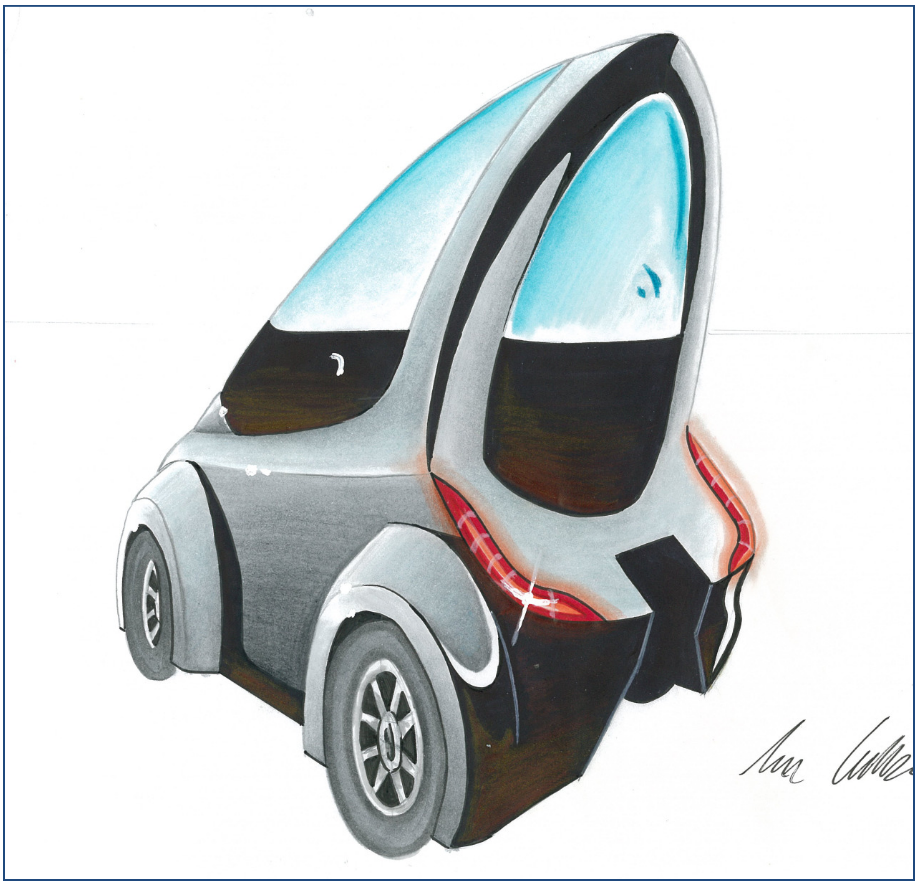


Figure 7.36: Rear view of the final Nano-RUF concept

The image over leaf best displays the flared back of the Nano-RUF design. This allows multiple vehicles to drive together closely thus reducing air resistance and the amount of energy required to operate. It also allows the vehicles to couple together closely during bends and inclinations. An example of the rear lights is displayed in this image.

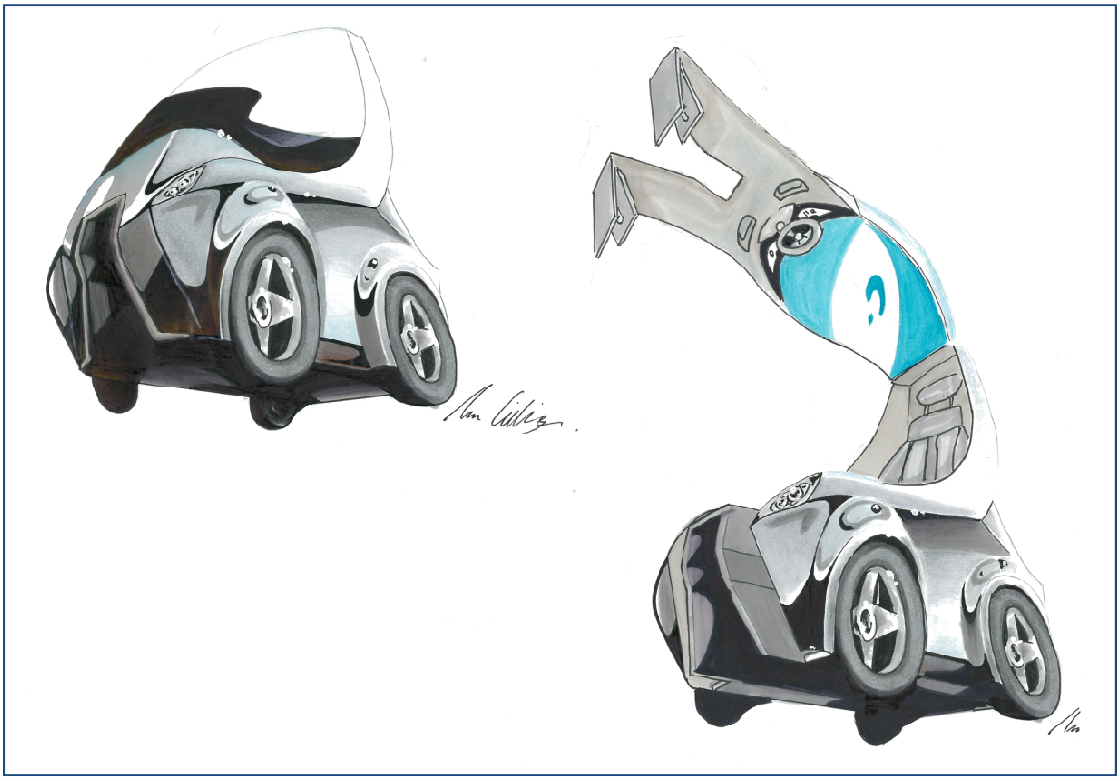


Figure 7.37: A pen render showing the door operation of the final concept

This pen rendered image describes the operation of the door mechanism. A small glimpse of the cabin is also available. This view also depicts where the position of the driver is located relative to the body of the vehicle.

8. Technical Design

8.1. Systems and Main Components

In order to achieve the main requirements for the design of the Nano-RUF technical innovations must be taken. In this section the main systems of the vehicle will be shown and the technological solutions explained.

The main innovation is the use of drive-by-wire systems and in-wheel motors which allow saving space.

In this chapter the systems that are closely related with the adaptation to the monorail are not included. These aspects are discussed in Section 7.4.

8.1.1. Power Plant

The power plant of a vehicle is what provides the power to propel it. It transforms the energy stored in e.g. gasoline or batteries into force and movement.

Throughout automotive history, power plants have evolved from horse power to electric motors through steam engines [Mitchell 2010].

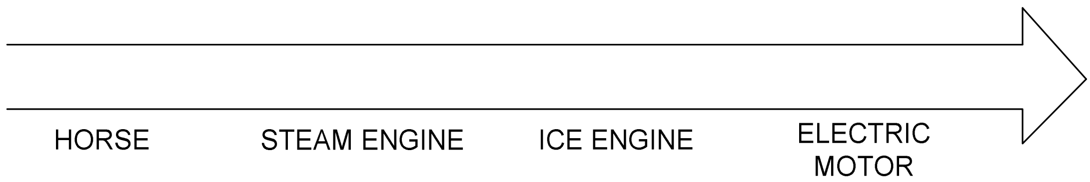


Figure 8.1: Historical evolution of vehicle power plants

Nowadays, most of the motorized vehicles are powered by internal combustion engines (ICE's) which use combustible petroleum derivates. Although their wide use, they have a low efficiency (around 28% [Garret2001]) and the gases generated by the combustion are highly pollutant and one of the main causes of global warming.

As far as electric motors are concerned, their efficiency is so much higher as ICE's efficiency. An electric motor working in proper conditions can achieve efficiencies higher than 90%. Of course, it has to consider the efficiency in the generation of the electricity and the efficiency of the electric transport system. Though depending whether the generation of the electricity is made by renewable energies or by classic thermal plants, the energetic efficiency of an electric vehicle can be considerably higher in comparison with ICE propelled vehicle.

Furthermore, the use of electric motors allows a change of shape in the modern vehicles, leaving behind the traditional engine under the hood and giving path to new options of design [Mitchell 2010].

Applying these considerations in accordance with the requirements for its design, the Nano-RUF will be propelled by electric motors and due to the limitation of space the best option will be to work with the so-called in-wheel motors.

In this power plant layout the motors are located inside the wheels and their work is directly transmitted to them. Moreover, the advanced technology of control for electric motors allows it to manage without gear boxes.

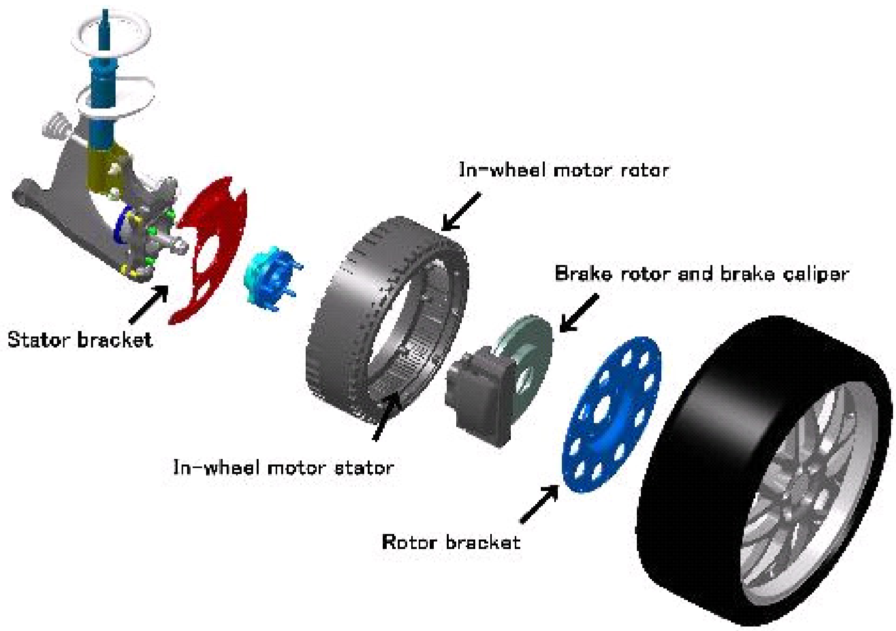


Figure 8.2: Layout of an in-wheel motor (Source: http://jcwinnie.biz/wordpress/?p=2211)

In-wheel motors have disadvantages like a high un-sprung weight. That means terrible handling and reduced road-holding capabilities. But for an application of low dynamic requirements like it is the Nano-RUF case, this factor should be minimal.

There is a large range of electric motors, a main classification is:

DC motor

It is the simplest motor and it is very easy to vary its speed, but it has losses because it needs a system of brushes and conmutator to work. The coils are located in the stator meaning bad refrigeration and thus bigger dimensions.

AC synchronous motor

Its speed depends on the frequency of the AC current, so it is easy to vary, but if the dynamic requirements change the speed of the rotor in reference to the frequency, the motor stops.

AC asynchronous motor or induction motor

It is the most common motor in the industry. In the past it was difficult to vary its speed properly but nowadays controllers make it easily possible.

Any of them can easily work as a power plant for an electric vehicle because the modern control techniques can make an accurate control of the speed and torque of each type of motor. Due to the special requirements of the Nano-RUF it is necessary to work with motors with high power and low volume i.e. power density. It can be achieved by using the Brushless DC Motors (BLDC). This kind of motor solves the problems of a DC motor. Arranging the coils in the stator and replacing the brushes and the conmutator for electronic sensors and power electronics, which invert the direction of the current exactly when it is needed. This motor is a kind of hybrid between a DC motor and an AC motor, it has the same structure as a synchronous motor with permanent magnets in the rotor, coils in the stator and it has a speed, torque characteristic very similar to a “brushed” DC motor.

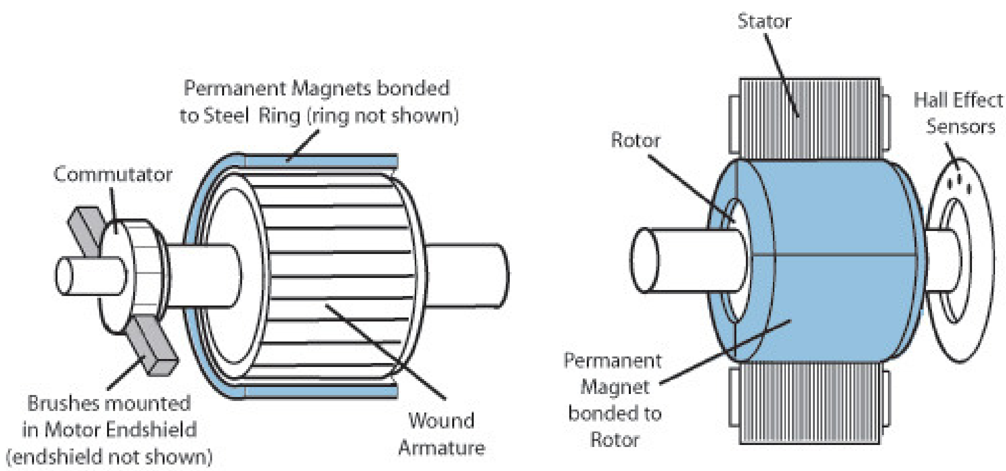


Figure 8.3: Constructive differences between conventional DC motor and BLDC motor (Source: http://www.orientalmotor.com/technology/articles/AC-brushless-brushed-motors.html)

Due to the special characteristics of an in-wheel application the conventional cylindrical architecture of an electric motor has to be replaced by a disc or ring shape.

Figure 8.4: Examples of ring and disc DLDC motors (Sources: www.iskra-ae.com, http://kellycontroller.com/car-hub-motor-72v-7kw-p-711.html)

In conclusion, the BLDC motor offers satisfactory responses to the requirements of an in-wheel motor, it is the most used in these applications and it is expected to be the type of motor for the power plant of the Nano-RUF.

In order to achieve a variable speed, a controller will be necessary for each motor. Mainly controllers are based in solid-state switches like transistors or new generation switches such as IGBT's. These controllers are able to transform DC current from the batteries into currents with proper waveforms to feed the motors and obtain the performance desired in each moment. This part of the controller is called inverter.

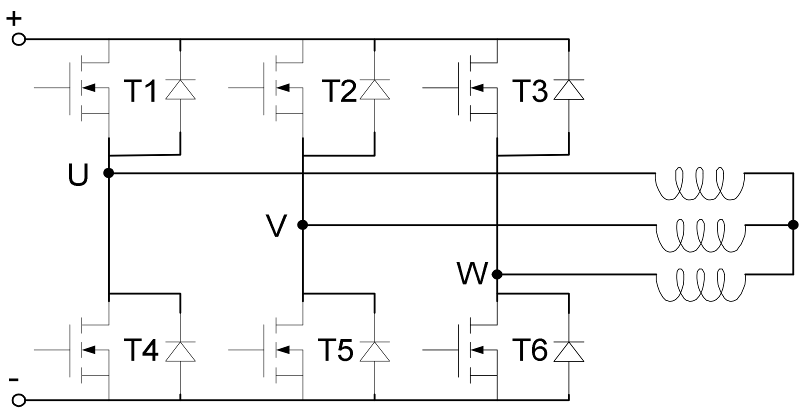


Figure 8.5: Schematic construction of a 3 phase inverter

The switches of the inverter can be controlled by several control strategies depending on the application or on the accuracy desired for the control. For automotive applications it is necessary to have a closed loop control. Speed sensors, current sensor and position sensors obtain the data from the motor in each moment and the controller adapts the supply in order to match the performed speed with the commanded speed.

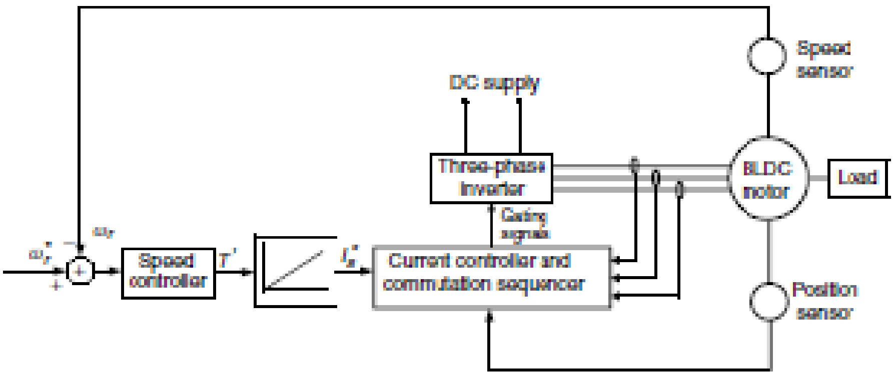


Figure 8.6: Block diagram of the speed control of the BLDC motor [Ehsani 2004]

The controllers have to be able to work in 4 quadrants. That means that the motors are required to make the vehicle move in a forward and backward direction, and to provide positive torque to accelerate and overcome the resistant forces and negative torque to brake. When the motors are working in the braking quadrants (negative torque) they work as generators using the kinetic energy of the vehicle to generate electric energy which is restored in the batteries. This is the regenerative braking.

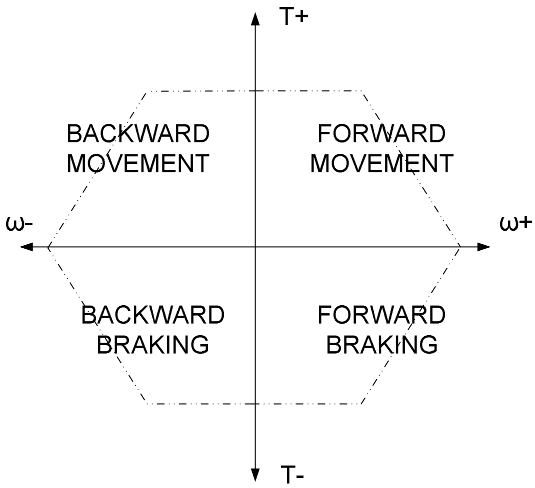


Figure 8.7: Four quadrant operation

As a summary, the power architecture of the Nano-RUF will be as shown in Figure 8.8.

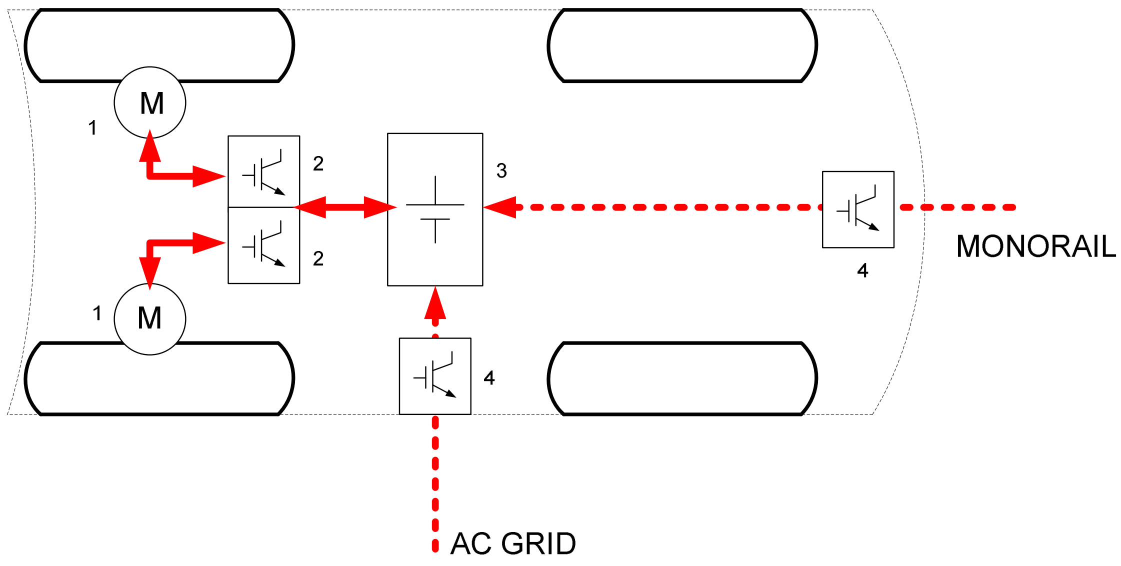


Figure 8.8: Schematic power layout for the Nano-RUF

The electric energy is recovered from the AC grid by means of a home plug or in a charging station or from the monorail when it is driving on it. The electric current from both sources must be adapted (4) to the DC voltage of the batteries and also must be limited (4) depending of the state of charge of the batteries.

This DC current from the batteries (3) will be adapted according to the driving requirements and transferred to the motors by the power electronic controllers (2).

The in-wheel motors (1) will work at the required speed and torque conditions and propel the vehicle.

The flow of energy is reversible in order to restore the energy from the regenerative braking.

8.1.2. Batteries

An electric vehicle like the Nano-RUF needs an energy storage device in order to have an energy source for its journeys. This is the main function of the batteries.

Batteries are electrochemical devices that convert electrical energy into potential chemical energy during charging, and convert chemical energy into electric energy during discharging [Ehsani 2004].

Batteries are the critical point in electric vehicles due to the difficulties for storing electric energy at a large scale and in an efficient way. However, throughout the years the development of more efficient, less heavy and bulky storage systems has been improved and it seems that these improvements will continue in further years.

The main battery technologies are the following [Ehsani 2004]:

- Lead-acid: The lead-acid battery is the most common commercial battery and is still widely used as electrical energy storage in the automotive field and other applications. Its advantages are low cost, mature technology, relative high power capability and good cycle.

  They also have several disadvantages. The energy density of lead-acid batteries is low and the presence of highly corrosive sulphuric acid is a potential safety hazard for vehicle occupants. Moreover, their components are highly pollutant.

- Nickel-based: Nickel is a lighter metal than lead and has very good electrochemical properties desirable for battery applications.

- Lithium-based: Lithium is the lightest of all metals and presents very interesting characteristics from an electrochemical point of view. Indeed, it allows a very high thermodynamic voltage, which results in a very high specific energy and specific power.

The main parameters of batteries are:

- Voltage (V): It is the voltage at the battery terminals, which is a function of the battery current and SOC.
- Capacity (Ah or Wh): It is the electric charge that the battery can supply.
- Specific energy (Wh/kg): It is defined as the energy capacity per unit battery weight. It is important in electric vehicles because it is a determining factor for their driving range.
- Specific power (W/kg): It is defined as the maximum power per unit battery weight that the battery can produce in a short period.
- Internal resistance (Ohm): It is the electrical resistance of the components of the battery. It leads to a voltage drop when a load is connected to the terminals of the battery.
- State of discharge (%): Or SOC, is an indicator of the remaining capacity over the total capacity of the battery.

A battery is composed of several cells stacked together. A cell is an independent and a complete unit that possesses all the electrochemical properties.

All electric cells have nominal voltages which gives the approximate voltage when the cell is delivering electrical power. The cells can be connected in series to give the overall voltage required. Traction batteries for electric vehicles are usually specified as 6V or 12 V, and these units are in turn connected in series to produce the voltage required [Ehsani 2004].

Depending on the type of connection of the cells the total voltage and capacity of the battery will be arranged. Both serial and parallel connection can be combined in order to achieve the desired parameters.

- Serial connection: the voltage is increased.
- Parallel connection: the capacity is increased.

To avoid high currents and consequently bigger wire sections due to the Ohm's Law it is interesting to work with a high total voltage in the terminals of the battery. The Nano-RUF battery will work with voltages of about 200 V.

So, a logical strategy in the choice of batteries for the Nano-RUF could be to dimension it taking into account the best modern battery technology. The future developments will imply cheaper, lightweight, and more power density batteries.

In order to estimate the weight and the driving range of the vehicle, high performance Lithium batteries will be used. Typical data of these batteries is following [Ehsani 2004]:

	High power batteries	High energy batteries
Specific energy	85 Wh/kg	150 Wh/kg
Specific power	1350 W/kg	480 W/kg

Table 8.1: SAFT Li-ion batteries specifications

As it is explained, the internal resistance and the SOC of the battery cause variations on the voltage, but these variations will be considered contemptible in the calculations since they are only approximations of the real performance of the system.

8.1.3. Steering

Common steering systems using mechanic or hydraulic systems are bulky and require a great amount of space. Thus, the solution adopted is to use steer-by-wire systems.

Other advantages of the electrically operated steering are the unlimited different adjustments that can be programmed for each different use. For instance, two different modes are needed for the use on the road and the monorail system. This also saves the need to install another motor and other control devices that move a regular steering system to guide the vehicle when it is used on the monorail.

The steering can also be setup to be adapted to the driver's tastes, having an option for quicker, livelier responses for sporty drivers or a more relaxed and slower reacting response for easy-going users. Another feature can be tailor made to the user's tastes is the steering resistance or opposing force needed to move the wheel, which can be very different from one young driver to an elderly one.

Other interesting setup possibilities are the active toe setup while the car is turning, to extract the maximum available stability of the chassis while remaining an easy, safe drive. The two separate steering modules for each turning wheel allows for this kind of adjustments.

A setup which applies toe into the inside wheel (or reducing the angle the inside wheel would usually turn) while turning can increase stability, giving a more surefooted impression to the driver and making the user more confident while driving the Nano-RUF. This setup will not be adjustable for the users, as it is part of the safety features.

The angle of steer has to be considered because it has a repercussion on the space available on the floor of the vehicle. The turning wheels are located very near where the driver locates its feet against the brake and accelerator pedals. This has created a problem of space, since the steering lock needed in order to comply with which regulations which state that the turning circle must be of how many meters, reduced the foot width's space to a mere 7cm. To prevent this, a specifically higher floor in this area has been proposed, in which, thanks to the triangular shape of the main beam, should offer a bigger space for the driver's feet.

Other proposed options are to relocate the user's foot forwards, straight into the pedals horizontal footrest, which are located in the vehicle's door (located at the front of the vehicle), making the legs more horizontally stretched, giving a more sporting driving position. This would have to be studied carefully to assure that it is comfortable for drivers of any age.

Another discarded solution was four wheeled steering, allowing for lesser angles on the front tyres, thus giving better foot space. This solution has been discarded for its higher cost of developing and manufacturing a further two steering wheels, but crucially because 4WS (four wheel steer) is only suitable to be used as an aid to the front tyres steering angle and can only be used when this front steering angle is bigger than at the rear wheels.

8.1.4. Suspension

Suspension systems have the same problem as steering systems because they tend to be extremely bulky.

The constraints found for implementing a regular system have already been explained in Chapter 7. Taking as inspiration prototypes developed by Siemens-VDO or Michelin the suspension system will be integrated in the wheel.

This also integrates the braking, steering and electric motors inside the rim. This creates an enormous amount of un-sprung weight, which induces to a compromised handling. Fortunately, the lack of heavy driveshafts reduces the un-sprung weight significantly.

A suspension system can be represented, in simplified form, as illustrated in Figure 8.9 by two degrees of freedom, which considers the sprung mass of the vehicle (consistent mainly of the body and all of its components) and the un-sprung mass which is mainly the tyres and the suspension.

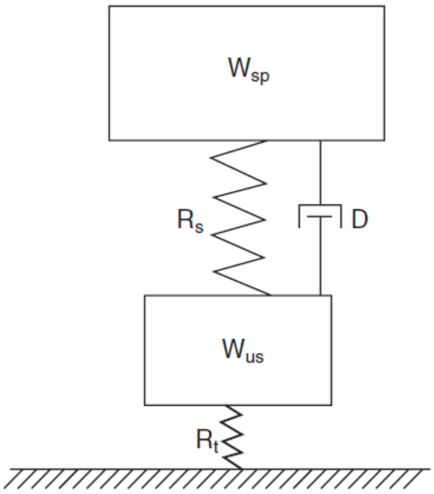


Figure 8.9: Simplified suspension system. Two degrees of freedom of movement [Garrett et al. 1997]

The natural frequency of the sprung mass is determined by the combined rate of the tyres and the suspension springs in series, which is:

$$\frac{1}{R}=\frac{1}{R_s}+\frac{1}{R_t} \tag{8.1}$$

Where R is the overall suspension rate, Rs is the suspension spring rate and Rt is the tyre rate. In Figure 8.9, Wsp is the sprung weight, Wus is the un-sprung weight and the shock absorber is the hydraulic damper at D.

Any friction in the suspension system will be additional to the hydraulic damping. Whereas the hydraulic damping force of the shock absorber can be taken as proportional to the square of the vertical velocity of the sprung mass relative to that of the un-sprung mass, the dynamic friction damping force is, in effect, constant regardless of velocity. It follows that while small amplitude, small velocity movements of the suspension are virtually unaffected by the hydraulic damping. The force applied by the friction damping is the same for these small movements as it is for large ones [Garrett et al. 2001].

The greatest challenge for implementing a new system such as this is that every reference found in books is based on existing solutions which cannot be taken as comparable systems. In order to make an approximate model of the suspension, as shown in Figure 8.10, a conventional double wishbone layout with longer than usual arms can be used to simulate the single vertical movement of the Nano-RUF layout with jacking points that are outside of the vehicle.

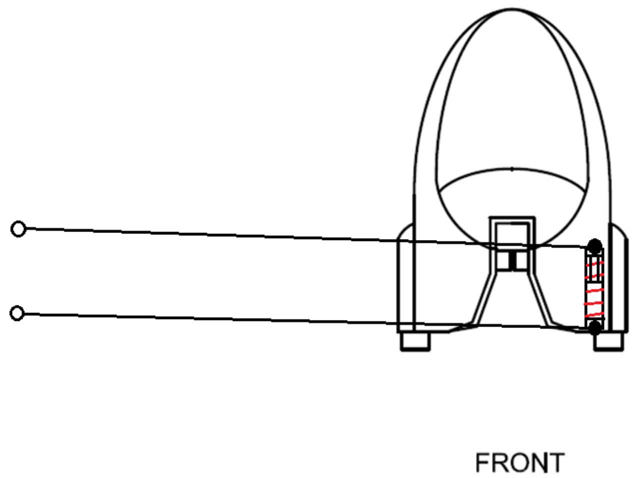


Figure 8.10: Suspension movement can be modelled as a conventional double wishbone system with very long arms, to simulate a single vertical movement of the suspension

Stroke of the suspension is limited due to the constraints of the design, although thanks to the use of a big rim (15 inches or 381mm), the compression and extension strokes are reasonable for a vehicle of this kind.

Compression is also limited from the wheelarches clearance, which is 100mm. Extension stroke is 250mm. It is larger than compression stroke in order to be able to cope with potholes and other road rough surfaces in comfort and safety with a long travel of the wheel which will cushion the passenger.

The remaining 30mm is to be able to have some space for the coil-damper strut arrangement and for the installation of rubber bump stops to soften the reactions in case the suspension runs out of stroke and reaches its upper or lower limits.

Rubber bump stops are especially important in the upper (bump) limit. If these do not absorb the impact well enough, an uncomfortable, bouncy ride will be transmitted to the vehicle's body and thus, to the user.

Due to the high height of the Nano-RUF, stability has been a major concern. In order to make the car more stable, an anti-sway (also known as anti-roll bar) system was proposed. Unfortunately, due to the hollow beam design and the need of the sway bar to connect both extremes through a beam that would be across the hollow space in the chassis, it is not possible to apply this solution.

Harder dampers all round should help control the lateral movement of the vehicle without compromising the ride excessively. Dampers have a two-fold function. First, they are for reducing the tendency for the carriage unit to continue to bounce up and down on its springs after the disturbance that caused the initial motion has ceased. Secondly, they prevent excessive build-up of amplitude of bounce as a result of periodic excitation at a frequency identical to the natural frequency of vibration of the sprung–mass system. This natural frequency is a function of the weight of the sprung mass and the spring rate, and in fact can be shown to be directly proportional to $1/\sqrt{\delta}$, where δ is the static deflection of the spring [Garrett et al. 2001]. The proposed active steering that can modify the toe of the inside wheel will also help for this matter. The high concentration of the mass of the vehicle in its lower parts with the location of the batteries, drive train, etc, should help lower this value enough to make it stable at the speeds it is designed to commute. As mentioned before, the higher speeds reached at the monorail should not be a problem since the car is tightly held to the rail by the clamping tyres, which prevent it from derailing at high speeds.

Although a calculation for the Centre of Gravity was interesting for this project, in order to be measured it would need to be done on a full sized prototype Nano-RUF, jacked as seen in Figure 8.11. The equation, according to Reimpell [Reimpell et al. 2001] to estimate the CoG's height will be:

$$h_v = \frac{l}{m_{v,t}} \frac{\Delta m}{h} \left(l^2 - h^2\right)^{1/2} + r_{dyn} \tag{8.2}$$

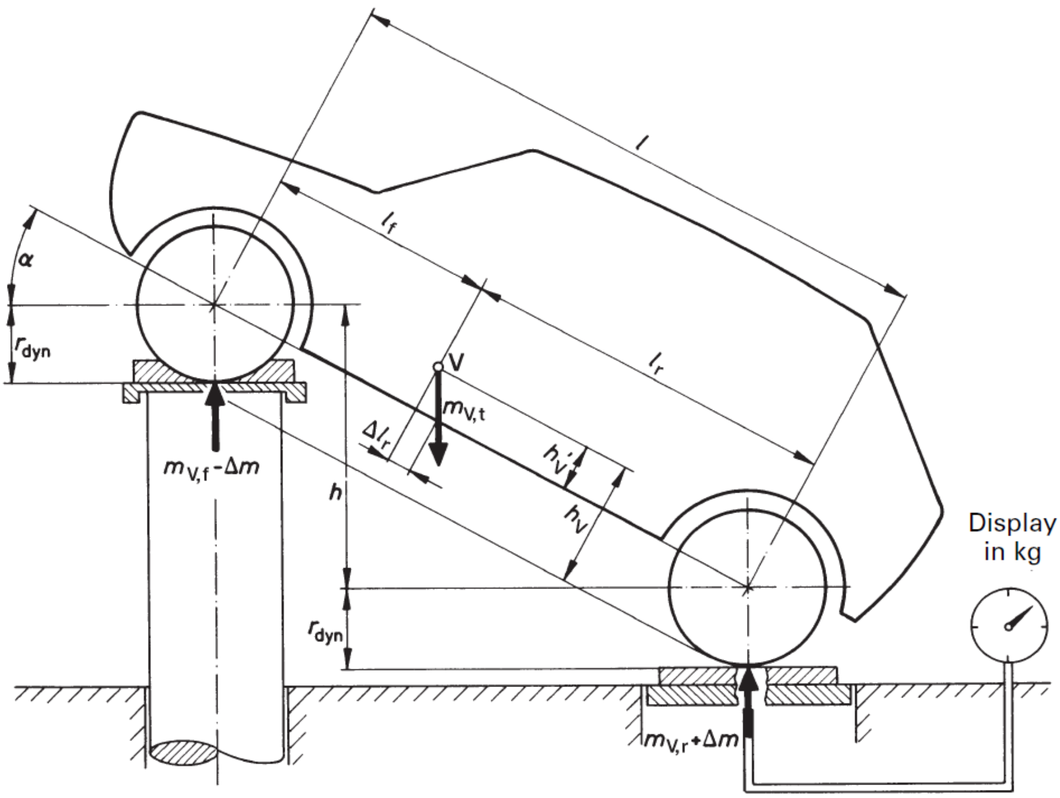


Figure 8.11: Vehicle on a weighbridge forces and paths for deriving the equation for vehicle centre of gravity height included

Unfortunately, the lack of knowledge for the weight of some components and crucially, lack of time and budget constraints made it impossible to complete this task.

8.1.5. Brakes

For the braking system, the traditional hydraulic systems for braking will be replaced for brake-by-wire systems. This reduces the need to install further sensors to control the purely mechanical braking systems, reducing the complexity, maintenance, and therefore affecting positively to the cost and weight of the vehicle. The lack of braking fluid makes the maintenance operation of bleeding unnecessary, thus reducing further costs while also ruling out possible issues that damage the braking capabilities of the Nano-RUF and therefore, making it both safer and more economical.

It is known that regenerative braking adds a lot of stopping power already from the tractive wheels (rears). Other electric vehicles that are already in the market that have the regenerative systems usually do not have the need to brake in most circumstances because of this, especially in city driving which is where the vehicle will be regularly driven.

The Nano-RUF only has power in its rear tyres, thus leaving the fronts with no stopping power. If an emergency brake was needed, an excessive stopping power from the rear tyres could induce the car to slide sideways in the same fashion a regular car is destabilised when the rear wheels actuating hand-brake is used. To be able to have a stable braking vehicle under all circumstances especially in emergency stops, electrically operated clamping pistons that make pressure on conventional steel discs will provide additional stopping power when the user requires it.

For surefooted braking, a modern ABS module will be installed. In case the system is triggered, it will distribute braking power on four wheels taking into account the following parameters: overall vehicle acceleration, steering wheel position and individual tyre speeds. The system will act accordingly distributing individually the exact amount of braking power on the electronically controlled braking front tyres and the regenerative braking rear tyres.

For the monorail use, higher speeds are attained and although the car will be driven automatically, thus reducing the need of stopping power, the clamping tyres also have electrical motors which, together with those of the rear tyres and the braking system on the front tyres will reduce stopping distances much faster in case a high speed emergency stop is needed.

The clamping tyres are not connected to the ABS system, thanks to the different layout and special conditions in which these wheels operate. To help even further, if an emergency stop is detected, the system will try to stop the clamping tyres as fast as possible, helped by the extra pressure from its clamping device, making an extra pressure to give an edge of grip and reduce the stopping distances even further.

8.1.6. Wing Mirrors vs. Camera System

The group considered some options to reduce drag. One option is the replacement of wing mirrors by rear-view camera systems. The following Figure 8.12 shows the view with the wing mirrors and different situations.

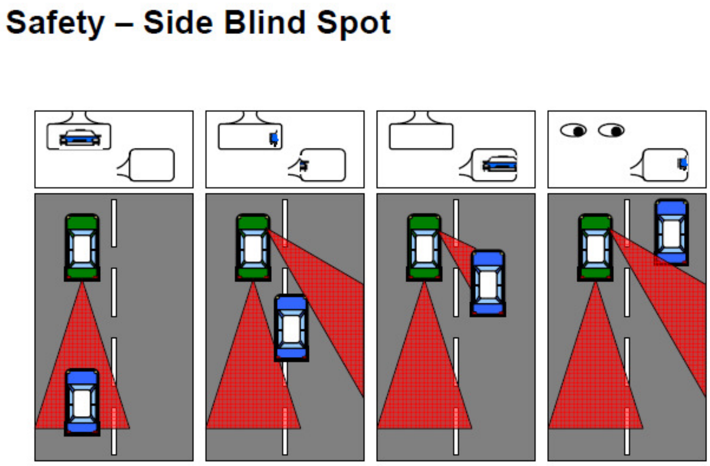


Figure 8.12: Side Blind Spot (Source [Selviah et al. 2007])

In some concept vehicles like the Infiniti Essence or the Hyundai Blue2 such systems are used. Tiny cameras could be assembled and a 360-degree view of the car's surroundings can be shown and seen by the driver on the car's dashboard [Ewing 2011, Paddock 2010].

As mentioned above, one advantage will be a further improvement of the aerodynamics as wing mirrors cause air resistance. The blind spot could be eliminated as well as the distortion, which means that objects in mirror are closer than they appear. Because the wing mirrors protrude from the vehicle, the driver would not have to worry about scraping something anymore.

Disadvantages of the system are the higher costs for the system than the traditional mirrors, that there is always a low latent delay from the camera to the display and that with vibrations there can be a change of the view [Selviah et al. 2007].

As the wing mirror has the purpose of helping the driver see areas behind and to the side of the vehicle, they are today considered as essential safety accessories [Machin 2010]. A totally mirror less car would have to meet safety standards before it could go on sale. Figure 8.13 shows the field of vision of a camera system.

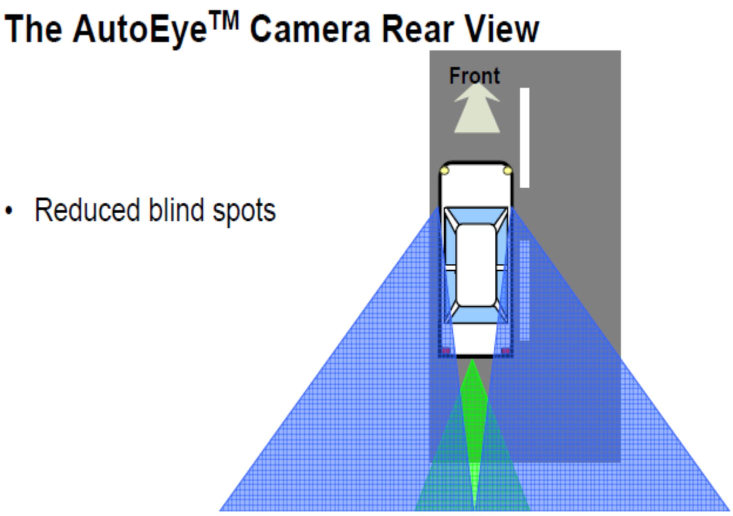


Figure 8.13: Camera Rear View (Source [Selviah et al. 2007])

OmniVision, the leading provider to the automotive industry in the Automotive Imaging technology, offers a 'Wing Mirror Replacement' application. This could be analysed for more detailed information.

Another possibility, which can be implemented, would be a folding wing mirror. Right now this option is implemented on some new premium cars. When they are parked, the wing mirrors are folded, so that the protrusion is reduced. For the Nano-RUF this change, done electronically could be used for the change from the road to the monorail. This is because on the monorail the side mirrors are not needed due to the automated drive. If the folded mirror would reduce the drag, this option would be more effective.

8.1.7. Lighting

In order to save the biggest amount of energy, the lights and indicators of the Nano-RUF must have a very low consumption.

Being a city car that will not go faster than 60 km/h, it is not needed to have an outstanding front lights package. It is very important though to have a design that allows the other road users to see the Nano-RUF and especially not to confuse it with a motorbike, due to its narrow design.

It has been considered that the best option could be the use of LED technology for its cost, energy consumption and compact features.

8.2. Size and Weight

To try to minimize the dimensions and the weight of the vehicle is one of the main requirements of the Nano-RUF.

This will allow a greater reduction of the consumption of energy through low air friction, rolling resistance and others resistant forces that are closely related with the size of the vehicle (see Section 8.1).

Thus, the dimensions of the vehicle are conditioned by two fundamental aspects:

- The anthropometrics of a person.
- The dimensions of the monorail.

In first stage sketches and designs (see Section 6.2) are focused on accomplish these requirements. Obviously, the system to adapt the vehicle to the monorail will affect also to the final design, but at this phase the design can only be based on speculations and assumptions.

The options to adapt the vehicle to the monorail are discussed in Chapter 8.5 but they will not be taken into account in the overall design of the Nano-RUF, mainly because there is no clear and satisfactory solution in this aspect. Thus, the dimensions of the designs presented in this report are essentially based on the requirements of the driver of the vehicle.

Said these considerations, the dimensions of the Nano-RUF based on the Engineering work that can be seen in detail in Appendix 8. A summary of these dimensions is shown in Table 7.2 and in Figure 8.14.

Height	1.80 m
Width	1.20 m
Length	2 m
Frontal area	1.90 m2

Table 8.2: Summary of the overall dimensions of the Nano-RUF

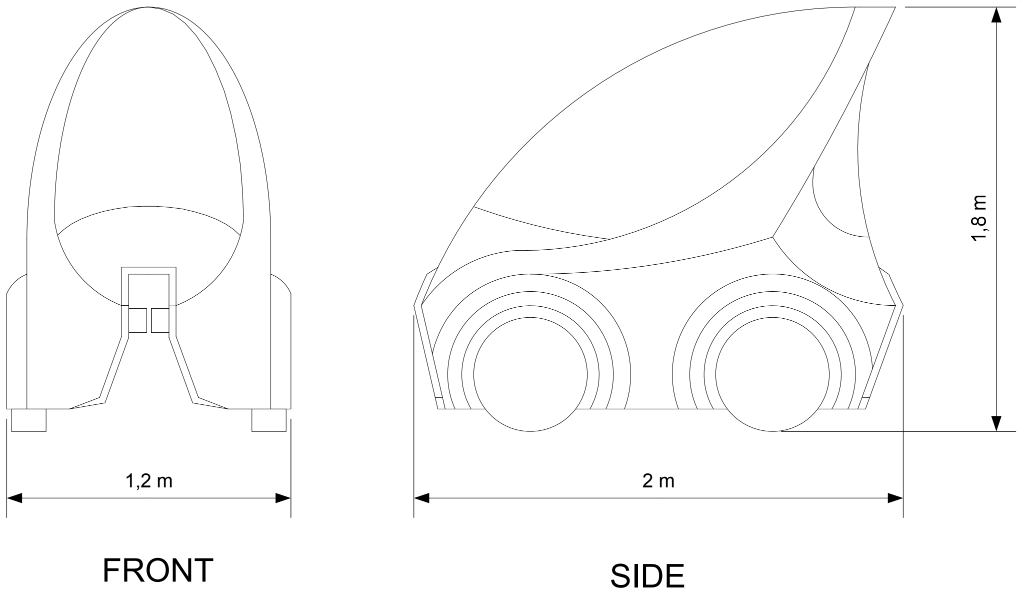


Figure 8.14: Overall dimensions of the Nano-RUF

To achieve a low weight is also a crucial aspect of the design of the Nano-RUF. It will mainly be compromised by the batteries and by the frame. Bearing in mind the necessity of a lightweight vehicle the batteries will have a high specific energy i.e. greater capacity for a low weight. The materials of the frame have to be lightweight. Other components such as the motors have been chosen in this direction offering high power with a considerable low weight.

An approximation of the expected weight can be seen on Table 7.3. It is based just on estimations of weight of the main components of the vehicle. The expected weight of the batteries has been calculated in the Section 8.3 according with the expected driving range of the vehicle. Despite the low accuracy of the calculation, the total expected weight is very close to the rated weight of similar electric vehicles such as the Renault Twizy which weighs 450 kg [Renault 2011].

Element	Expected weight (kg)
Batteries	60
Frame	90
Body panels	40
Motors	18
Wheels	40
Others	30
Controllers	27
TOTAL	**305**

Table 8.3: Estimation for the final weight of the Nano-RUF

Using as reference these estimations and the weight of similar vehicles in order to set a proper weight for the performance calculations, the weight of the Nano-RUF will be 400 kg including the passenger. However, the rated weight of the vehicle can be estimated as 350 kg.

As far as the wheels are concerned they require a generous rim size to fit the motor while at the same time a small width to have a low friction. The one that has been found to be most suitable to use with the in-wheel motor can be seen on the front tyres of the smart car. These tyres measure 145/65 R15 and are suitable for at least a maximum speed of 140 km/h, which is also a reasonable maximum speed for the Nano-RUF vehicle. This results in a wheel diameter of 480 mm.

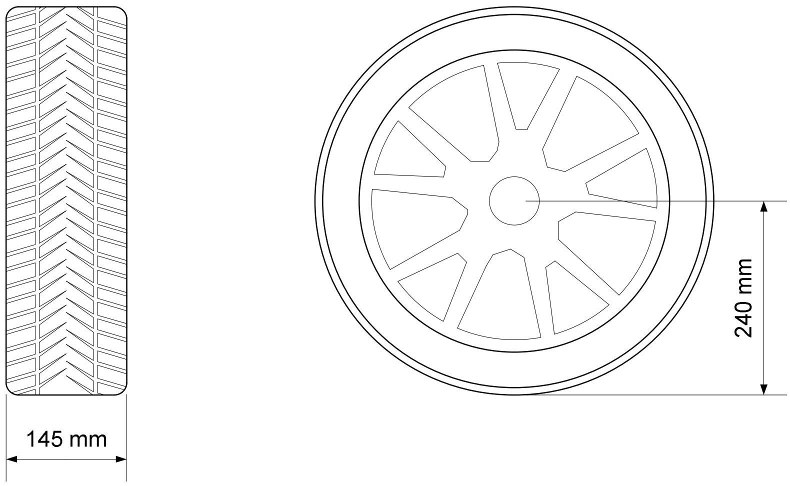


Figure 8.15: Wheel dimensions

8.3. Engineering Drawings

During the design phase it was necessary to construct some accurate drawings of the Nano-RUF. Once the final design was chosen it was then drawn using the correct measurements in AutoCAD. These drawings gave an accurate view of the Nano RUF shape and dimension and allowed the development of the chassis frame to be designed. This was possible by using construction lines and the shape of the RUF as an underlay and building the chassis around it.

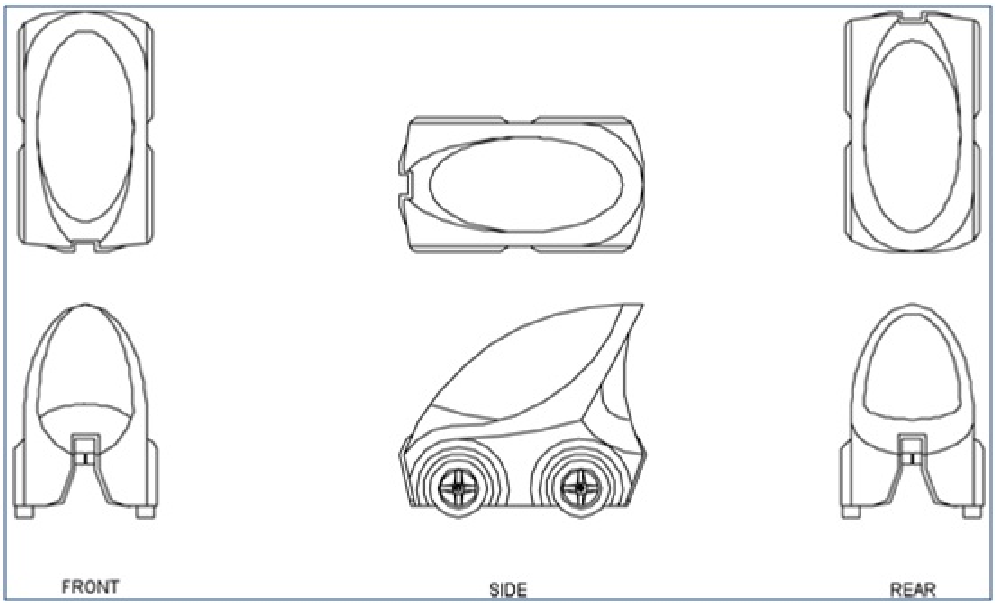


Figure 8.16: Engineering drawing of final RUF concept

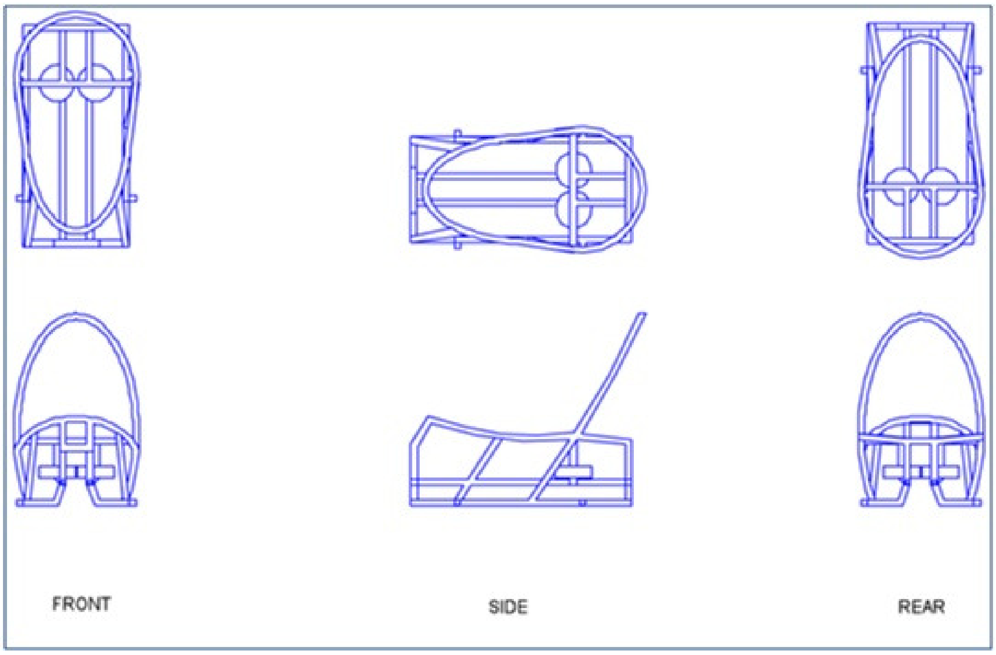


Figure 8.17: Engineering drawing of the internal frame of the Nano-RUF

Since the main structure of the RUF was built around the triangular frame it was naturally strong. This meant the design phase only required making decisions where extra support was necessary. For example the roof structure needed some form of roll bar for support. This was added in along with some struts to strengthen the overall shape. A diameter of 50mm, was used in racing roll cages for cars sanctioned by the FIA (Federation Internationale d'Automobilisme), so this was used as an estimate for the chassis tubing, as it would depend heavily on the material used. If an alloy was used it could be lighter, stronger and thinner then using a steel structure. This drawing also shows the position and diameter of the rail clamping wheels and the adjustable structure that positions them.

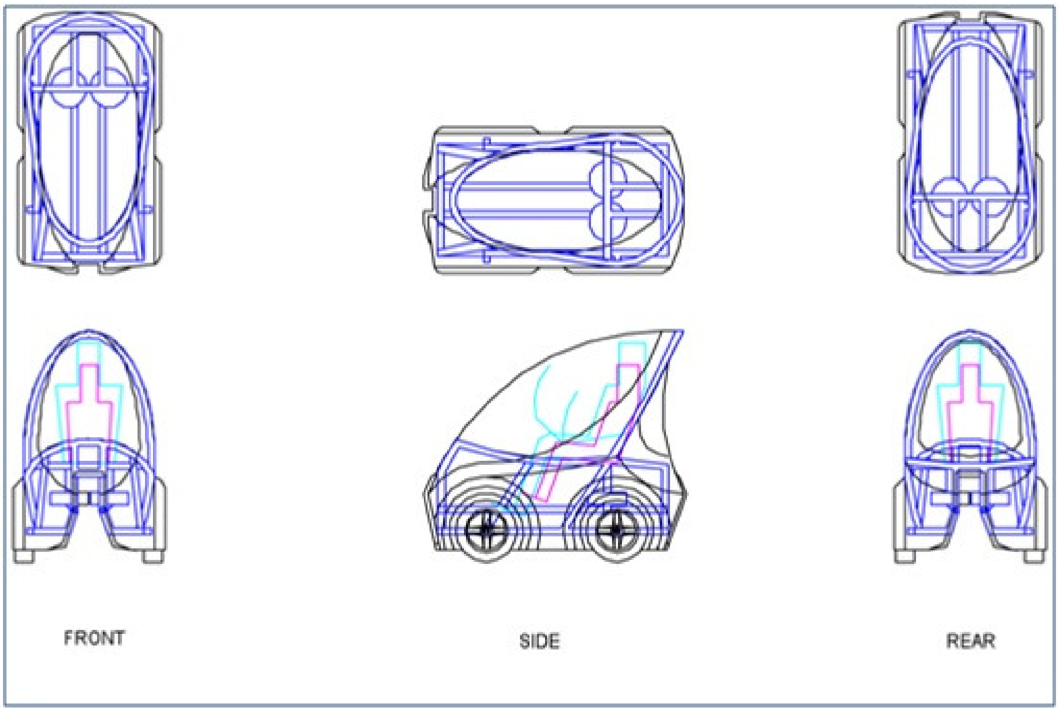


Figure 8.18: Engineering drawing including body link diagram, chassis structure and overall RUF shape

This drawing is the complete version of the Nano-RUF design. It shows the body positions of 5%ile female and 95%ile male passenger in relation to the overall shape and chassis of the vehicle. It can be seen that the vehicle is compact but still provides sufficient space for comfort without inhibiting technical performance. The drawing also shows range of movement for the passengers, which is important to the users comfort.

8.4. Chassis Design

Design of the main frame was a very important part, as it had to comply with many requirements. First of all, it had to be able to comply with the monorail measurements, be able to sit a passenger comfortably inside and all of the mechanical components (batteries, control units, etc). Some of the other requirements were to be strong enough to support the whole structure under any use and conditions. It should be tough enough to remain un-deformed around the passenger but at the same time to be able to absorb the energy under impacts caused by an accident. Crucially all of this had to be easy to produce, lightweight and as inexpensive as it possible.

For the floor and main beam structure that runs along the vehicle, a series of Alucore (aluminium honeycomb covered by a composite at each side) panels were chosen to isolate from the monorail system and use it as an inverted V to accommodate both the passenger seat and all of the interior components such as batteries. This floor is reinforced at both extremes by thicker panels and in every crease by a tubular beam to reinforce the structure and prevent from any buckling.

Surrounding the cabin space a tubular frame will be constructed to act as a roll cage and safety cell around the driver. It was decided to use a main tubular frame structure as a roll cage for safety, lightness, rigidity and simplicity reasons. A large tubular structure is ideal for torque transfer in a chassis when compared to chassis like the Lotus Elise which has a tested value of approximately 11kN·m/degree [Wakeham, 2009].

The design of this chassis is based on two main curves which start from the floor, which also has its own tubular frame for reinforcement purposes. preventing. The frontal roll beam is tilted to also protect from frontal crashes. These beams are reinforced laterally by triangulations from the side of the beams to the tubular frame in the floor, to prevent intrusion in case of side impacts. Finally, a rear beam located behind the main roll beam that reinforces the main structure will prevent intrusion from rear impacts. This safety chassis is the main core of the car and the mechanical components such as the drive train, batteries, suspension, etc will be attached to it.

Around this safety cell, body panels will be installed to isolate the driver in an enclosed environment. These panels will be made out of composite materials that are lightweight, noise isolating and recyclable materials. They must be inexpensive and easy to install, giving a quick solution for scratches and body repair. Since trends are a must for marketing purposes, these panels could be interchangeable at a cost for others with different colours that allow the user to personalise their vehicle anytime they want.

8.5. Adaption to the Monorail

In the first part of the project solutions to minimize the dimensions of the vehicle have been sought. Furthermore, the Nano-RUF has to be able to drive on the monorail of the RUF system. In this chapter the possible solutions to adapt the vehicle to the RUF monorail will be analysed and explained.

8.5.1. The Monorail

The current monorail for the RUF system has a triangular shape, it is made of steel and it is suited for being installed and supported by a concrete structure. Its dimensions can be seen in Figure 8.19.

It is originally designed to be able to support the bigger RUF vehicles such as Maxi-RUF or RUF (see Chapter 4).

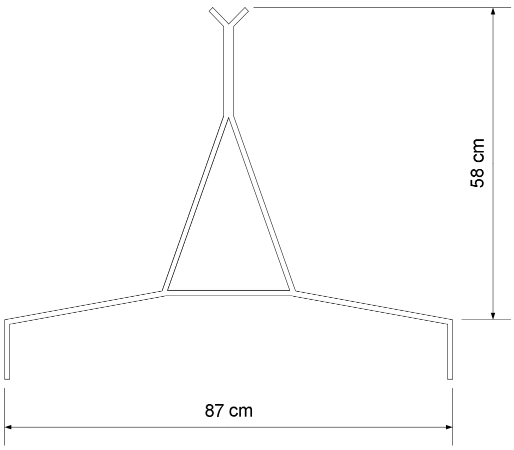


Figure 8.19: Monorail dimensions

The monorail has an angle in relation to the horizontal plane in order to evacuate rain or other substances derived from air pollution. Furthermore, this angle has been designed to stabilize the vehicle on the monorail (see patent in Appendix 2).

The already designed RUF vehicles use a clamping system which consists of two vertical axis wheels that clamp the vehicle to the vertical beam of the monorail. Those vehicles have also four extra wheels which act as support wheels on the monorail. All those wheels are part of the drive system of the vehicle and propel it.

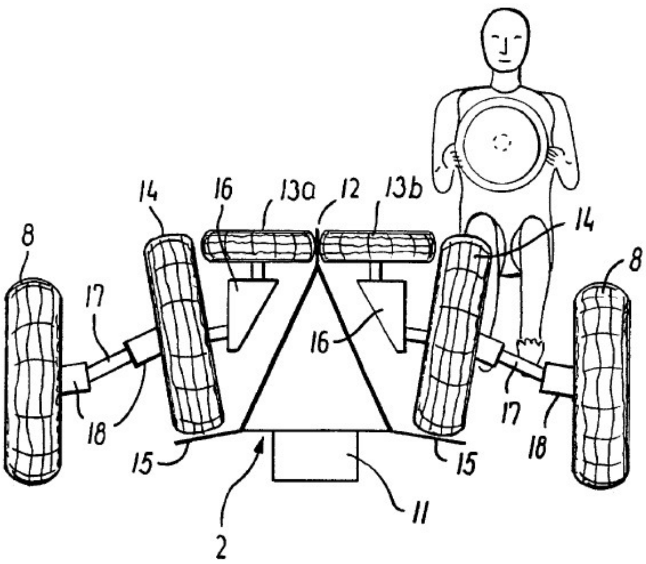


Figure 8.20: RUF drive system [Jensen 2003]

8.5.2. The Nano-RUF on the Monorail

After the first preliminary studies it appears that it is a big challenge to adapt a small vehicle to this monorail without compromising the space required for the driver, the stability and good traction of the vehicle.

Especially for the Nano-RUF, the current monorail restricts the size necessary for a person and presents a series of problems. The height of the central vertical part and the angle of the floor being the main restrictions.

The central beam of the monorail requires having a central hollow beam between the legs of the passenger that consumes a lot of space inside the vehicle and also forces to an uncomfortable position of the driver.

The angle of the monorail forces the design an additional drive system separate from the drive system on the road or to adapt it to the angle and the monorail drive. This is problematic in a very small vehicle because it requires extra space.

8.5.3. Options of adaptation

Different options of adaptation have been considered with the premise of keeping the current monorail untouched wherever possible.

a) <u>Direct adaptation</u>

This option considers just driving on the monorail without any changes on the on the road configuration of the vehicle. It is the simplest option because there is no need of duplicate the drive system or adaptation. The angle of the monorail could cause a high degradation of part of the tyres and a poor, unstable and inefficient traction. This option means an important restriction of the width of the vehicle considering its stability on the road (risk of rolling in the curves) and the space needed by a person.

b) <u>Tilting wheels adaption</u>

This option provides the vehicle with a tilting system for the four wheels. As well as in option a) the same wheels are used as the drive system on the road and on the monorail. Tilting the wheels it is possible to get a good traction on the monorail but it requires an electro-mechanic system and it also restricts the width of the vehicle in the same way as in option a). Furthermore, the repercussion of the angle of the wheels at high speed and whether it could compromise the security of the vehicle has to be studied.

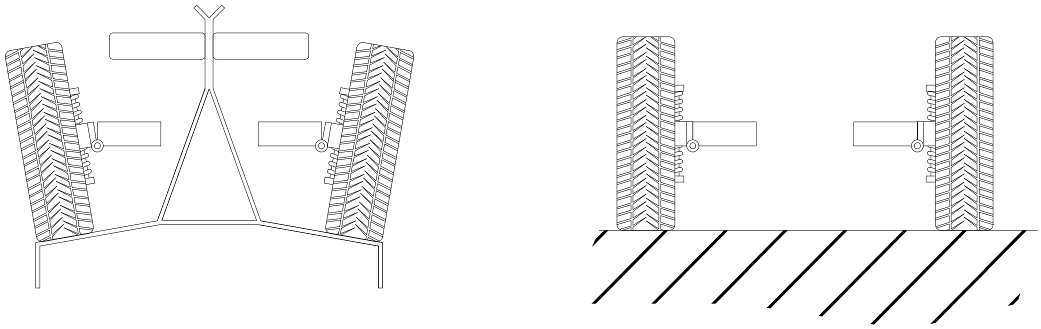


Figure 8.21: Tilting wheels adaption

c) <u>Wheels specially designed for the dual mode</u>

The angle of the monorail makes this option very difficult because it leads to a design with conical wheels which cannot work on a lineal movement due to the difference of radius between the internal and the external part of the wheel.

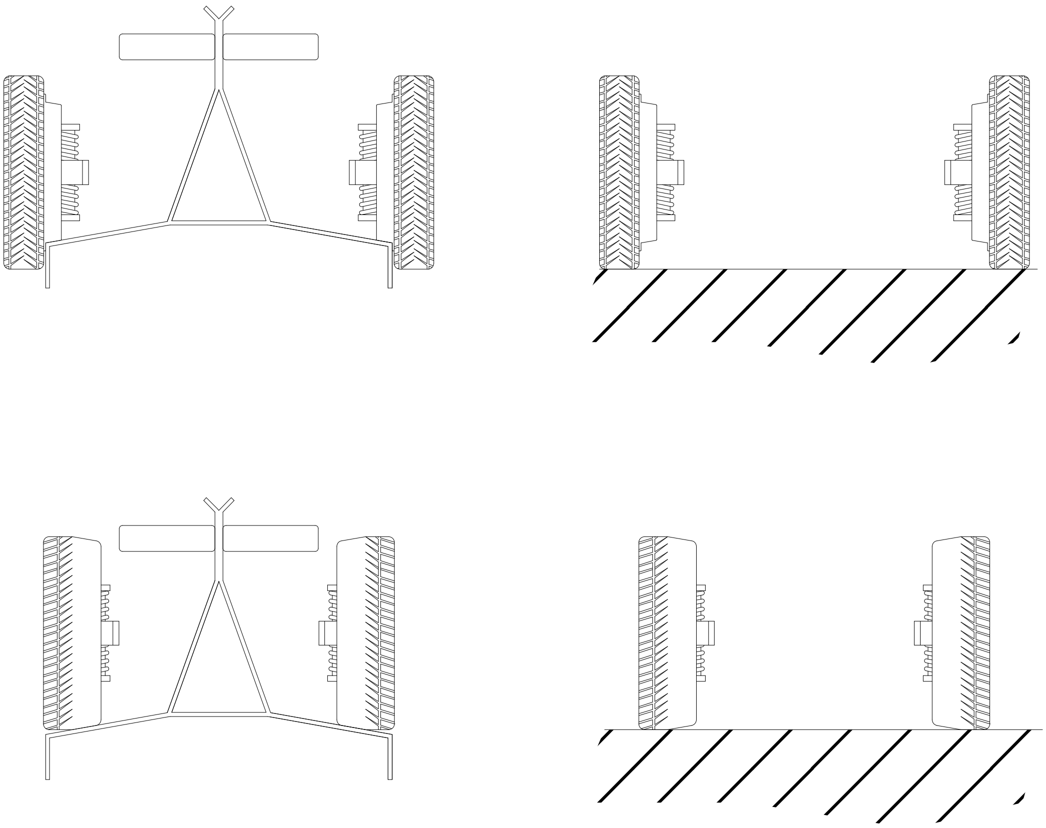


Figure 8.22: Dual mode wheels

d) <u>Duplicate the drive system</u>

As in the current RUF drive system, extra wheels can be added just for driving on the monorail but in the Nano-RUF's case it seems excessive to have a small vehicle with eight wheels and crucially it requires a lot of extra space.

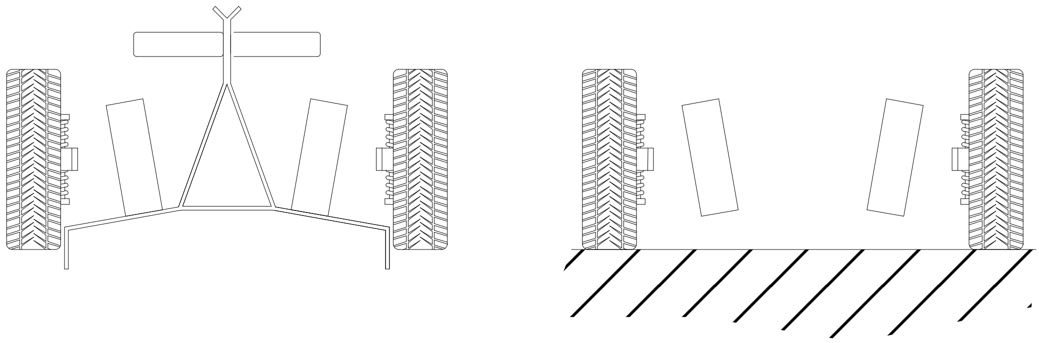


Figure 8.23: Double drive system

e) <u>Modifications on the monorail</u>

Using wheels adapted to the dual mode and a slight modification on the monorail or just by using classical wheels and increasing the width of the monorail horizontally.

This solves the major part of the design issues. It provides more width and there is no need of a duplicated drive system or to place electro-mechanic systems of adaption but it requires a modification of the current monorail and consequently of the patent.

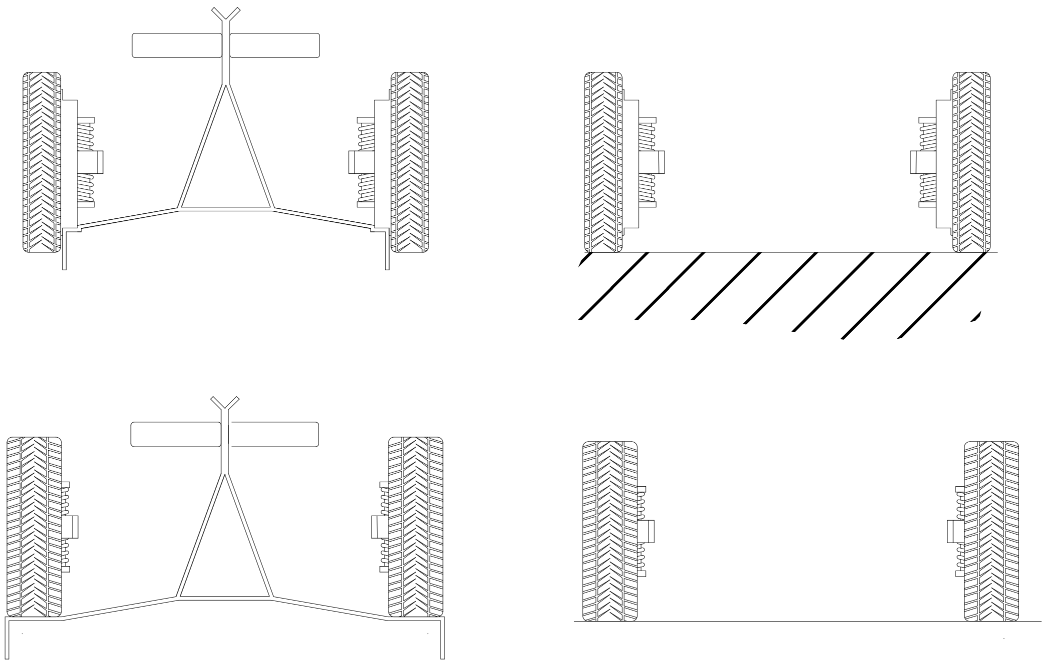


Figure 8.24: Modifications on the monorail

Of the different options no satisfactory solution has been found.

Although the easiest technical solution is to modify the rail, it is well known that the rail is the part of the system that requires greater investments but on the other hand depending on the role of the Nano-RUF in the whole RUF system the modification could be considered.

As far as the drive system for the rail mode is concerned, the proposed solution is to use the same wheels as drive wheels as on the road mode and use the clamping wheels without any tractive effort. Anyhow motorizing the clamping wheels can be considered. The clamping system has to be actuated by an electromechanical mechanism, a proposal can be seen on Figure 8.21 and it consists in motorized screw thread.

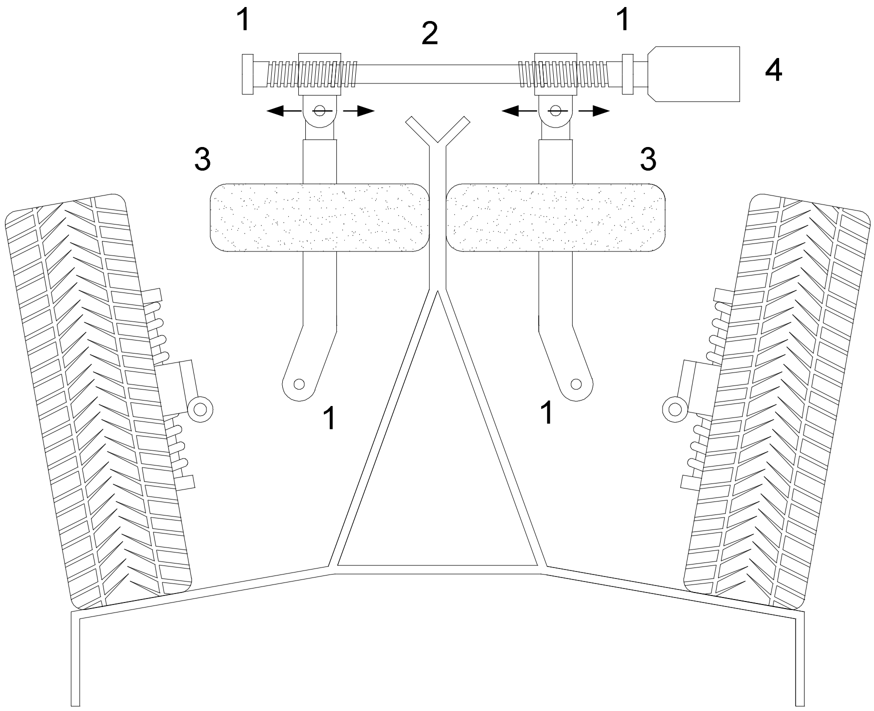


Figure 8.25: Proposal for clamping system

1.- Chassis supports

2.- Screw thread

3.- Clamping wheels

4.- Electric motor

Finally it has to be said that for the following dynamic study no specific solution has been used or taken into account. It has simply been considered that the drive wheels are the rear wheels and that these are rolling on the monorail.

9. Dynamics and Performance

The description of the design and technical aspects of the Nano-RUF will be analysed and studied in order to prove how they will affect the dynamics and performance of the vehicle. It will be done through mathematical equations and calculations that are only approximations because several factors are not considered. However it will give an idea of the real behaviour of the vehicle and will also help to size up the different main elements.

9.1. Tractive Effort

Tractive effort is the force propelling the vehicle forward, transmitted to the ground through the drive wheels [Larminie 2004]. This force must be at least equal to the resistant forces opposing vehicle's movement. Resistant forces are the following:

- Rolling resistance
- Aerodynamic drag
- Grading resistance

The vehicle's propulsion system must be able to provide the necessary force to accelerate the vehicle if the velocity is not constant.

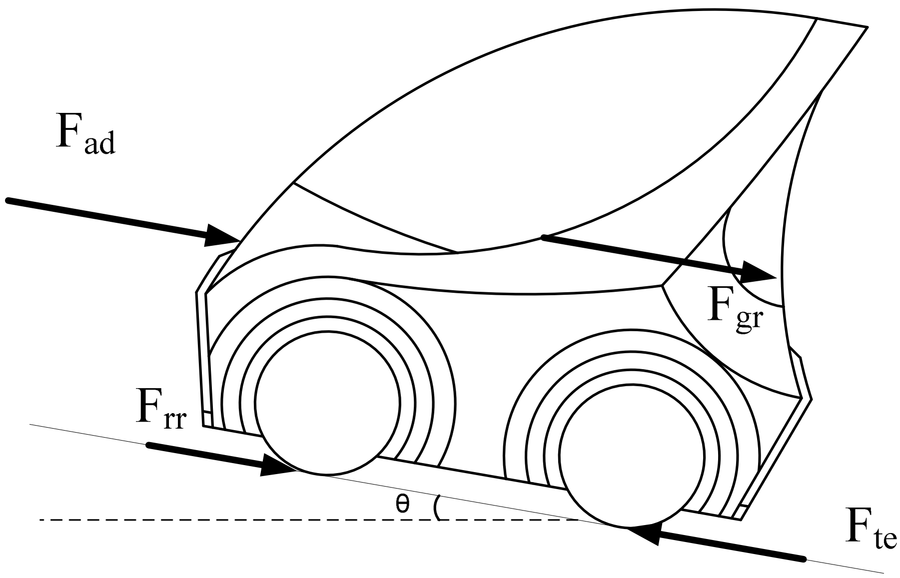


Figure 9.1: Main forces acting on a vehicle

__Aerodynamic drag__

The aerodynamic drag is the force due to the friction of the vehicle body moving through the air. It is functional of the frontal area, shape, protrusions such as side mirrors, etc. [Larminie 2004]. Its equation is:

$$F_{ad} = \frac{1}{2}\rho A C_d v^2 \quad (9.1)$$

Where:

F_{ad}: Aerodynamic drag force (N)
A: Frontal area of the vehicle (m^2)
C_d: Drag coefficient
f_r: 0,0055
ρ: Density of air (1,225 kg/m^3)
v: Velocity of the vehicle (m/s)

The aerodynamic considerations are extremely important in the design of a vehicle because they affect the proper dynamic behaviour of the vehicle and its energy consumption as well. As explained in Chapter 7.2 these considerations have been taken into account in the design of the Nano-RUF.

As a result of the aerodynamic design the drag coefficient (C_d) will be given. It is characteristic of each vehicle and depends of the layout and of aspects like surface.

To determinate properly the drag coefficient it is necessary to do it through accurate computer simulations or through empirical tests with the real vehicle or a scale model e.g. in wind tunnels. However, there are tables available with typical values of drag coefficients that can be useful for an approximated calculation.

Vehicle type	**Drag coefficient**
Open convertible	**0,5-0,7**
Van body	**0,5-0,7**
Ponton body	**0.4–0.55**
Wedge-shaped body; headlamps and bumpers are integrated into the body, covered under body, optimized cooling air flow	**0.3–0.4**
Headlamp and all wheels in body, covered under body	**0.2–0.25**
K-shaped (small breakaway section)	**0.23**
Optimum streamlined design	**0.15–0.20**

Table 9.1: Typical values of drag coefficient

The Nano-RUF design has a streamlined shape, so a low drag coefficient can be expected. According with the values of table 8.1 it will be considered a drag coefficient of 0,2.

This point should take into account the dual mode drive. When the Nano-RUF is on the monorail the drag coefficient will be extremely reduced to 85% of the drag coefficient considerate on the road drive mode [EPS, 2008]. This will reduce the resistant force, energy required and consumption when the Nano-RUF is on the monorail together with others vehicles. An approximate comparison can be seen on Figure 9.2.

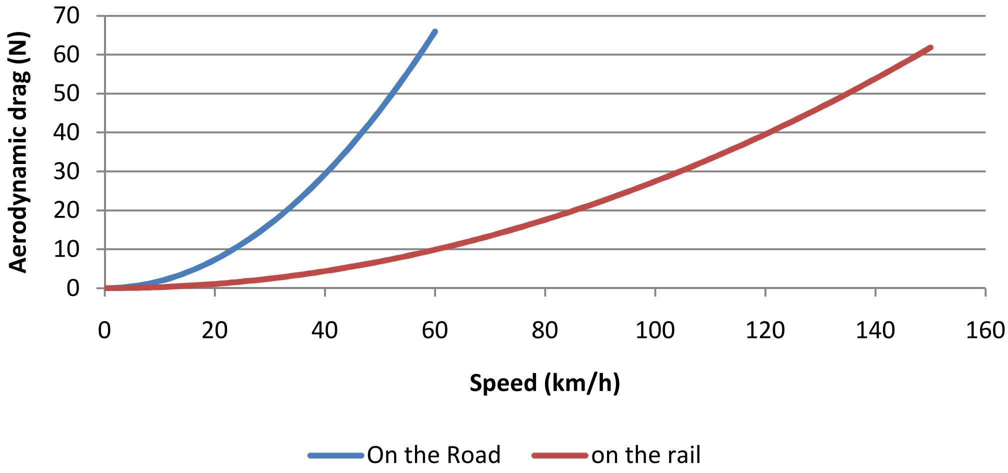


Figure 9.2: Comparative of drag resistance on road and rail drive

Rolling resistance

The rolling resistance is associated with the force necessary to overcome the friction of tyres [Larminie, 2004]. It is proportional to vehicle's weight and hardly related to speed. Its equation is:

$$F_r = m_v g f_r \qquad (9.2)$$

Where:

F_r: Rolling resistance (N)

m_v: Weight of the vehicle (kg)

f_{rr}: Coefficient of rolling resistance

g: Acceleration due to gravity

The coefficient of rolling resistance (f_r) depends of constructive aspects of the tyres such as material or width. Typical values can be found easily, and to make an estimation a coefficient of 0,005 typical for tyres of small electric vehicles will be used. [Larminie, 2004].

Grading Resistance

It is the force needed to drive the vehicle up a slope. It depends of the typology of the city where the vehicle is supposed to drive and will be given by:

$$F_g = m_v g \sin\theta \quad (9.3)$$

Where:

F_g: Grading resistance (N)
m_v: Weight of the vehicle (kg)
θ: Slope angle
g: Acceleration due to gravity

Clamping Wheels Resistance

While the vehicle drives on the monorail it has to be considered as a resistant force of the friction between the clamping wheels and the monorail.

$$F_{rcw} = F_{cw} f_{rrcw} \quad (9.4)$$

Where:

F_{rcw}: Clamping wheels resistance
F_{cw}: Force applied by the clamping wheels towards the rail
f_{rrcw}: Rolling coefficient of the clamping wheels

Anyway, this force seems to be low if there are used clamping wheels with a low rolling coefficient and will be considered contemptible.

Acceleration forces

When the vehicle changes its speed, i.e. accelerates, it needs to deliver an extra force in addition to the original force to overcome the resistant forces. This force is a transitory force that requires a peak of torque from the motors.

The lineal acceleration is given by the Newton's Law:

$$F_a = m_v a = m_v \frac{dv}{dt} \quad (9.5)$$

Where:

m_v: Weight of the vehicle
a: Linear acceleration
v: Speed of the vehicle

The angular acceleration of the motors has to be considered though it is usually necessary to know the moment of inertia of the motor.

$$F_\alpha = J\alpha = J\frac{d\omega}{dt} \quad (9.6)$$

Where:

J: Moment of inertia
α: Angular acceleration
ω: Angular velocity

It can be approximated by increasing the mass in the lineal acceleration (Equation 9.5) through a factor called mass factor (δ) that uses a value of 5%.

$$F_a = \delta m_v \frac{dv}{dt} = \delta m_v \frac{\Delta v}{\Delta t} \quad (9.7)$$

These forces will be negative when the vehicle is braking.

Total tractive effort

The addition of the resistant forces (Equations 9.1, 9.2 and 9.3) and the acceleration forces (Equation 9.7) will be the total tractive effort.

$$F_{te} = F_r + F_{ad} + F_g + F_a \quad (9.8)$$

If the performance is only considered in steady state at a constant speed and the forces substituted by their equations, the force required to the power plant is:

$$F_{te} = m_v g f_r + \frac{1}{2}\rho A C_d v^2 + m_v g \sin\theta \quad (9.9)$$

Where, according to the previous considerations in this chapter:

F_{te}: Total tractive effort
A: 1,9 m^2
m_v: 400 kg
C_d: 0,2
f_r: 0,0055
θ: Slope angle
ρ: 1,225 kg/m^3
g: 9,81 m/s^2

Using Equation 9.9 the tractive effort of the Nano-RUF when it is driving on the road and when it is driving on the monorail for different grades and speeds can be calculated. It is shown in Figure 9.3.

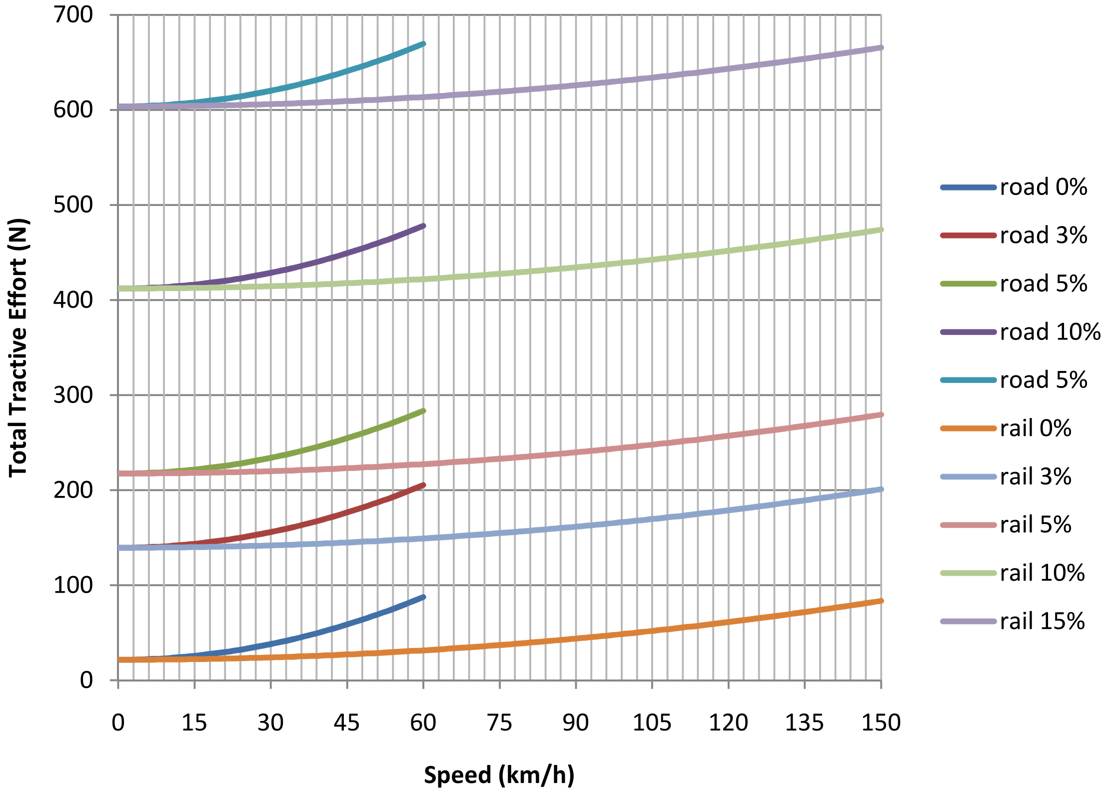


Figure 9.3: Nano-RUF's Tractive effort in different situations

9.2. Power and Torque

The power required to the power plant to move the vehicle is the function of the total tractive effort and of the speed of the vehicle:

$$P = F_{te}v \qquad (9.10)$$

As it is explained in Section 7.1.1 the drive system of the Nano-RUF will have a direct drive system so the torque will be directly transmitted to the wheels. The torque required to the drive motors will be:

$$T = F_{te}r_w \qquad (9.11)$$

Where:

T: Torque (Nm)

F_{te}: Tractive Effort (N)

r_w: Radius of the wheel (m)

According to Section 7.2 the radius of the wheel will be 0.24 m.

Once the power and torque requirements of the vehicle are known then the requirements for the drive motors of the vehicle can be calculated. The total power can be supplied by just two motors that will be arranged in the rear wheels. Each of the motors must be able to deliver half of the total tractive effort required and consequently half of the power and torque required.

It has to be noted that the power requirements are strongly related with the grading resistance. In order to estimate the mechanical requirements in continuous operation it will be considered a maximum slope for continuous operation of:

On the road: 15 %

On the rail: 10 %

As far as the maximum speed is concerned, it is supposed to be:

On the road: 60 km/h

On the rail: 150 km/h

After these considerations and taking into account Equations 9.10 and 9.11, the power and torque requirements for each motor as a function of velocity can be seen in Figures 9.4 and 9.5.

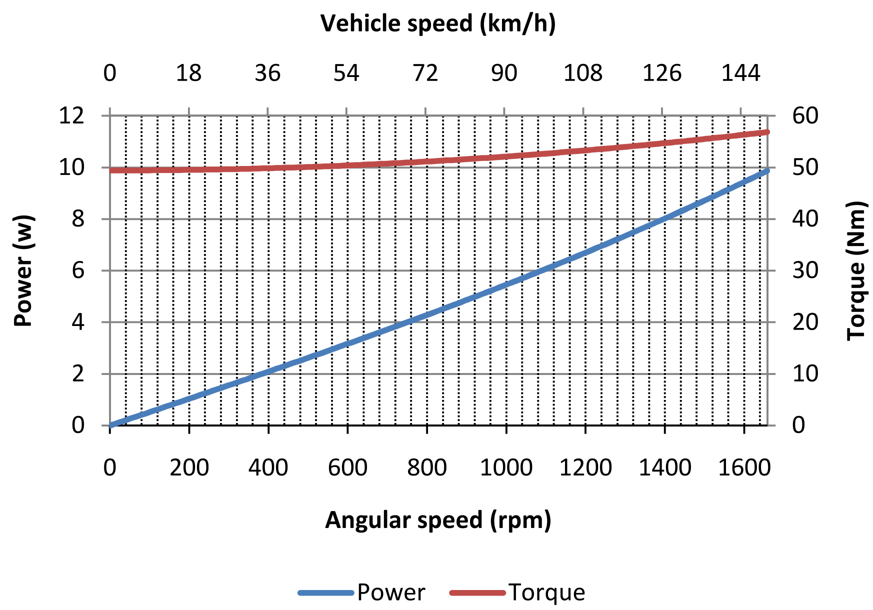


Figure 9.4: Power and Torque requirements for a drive motor on the road

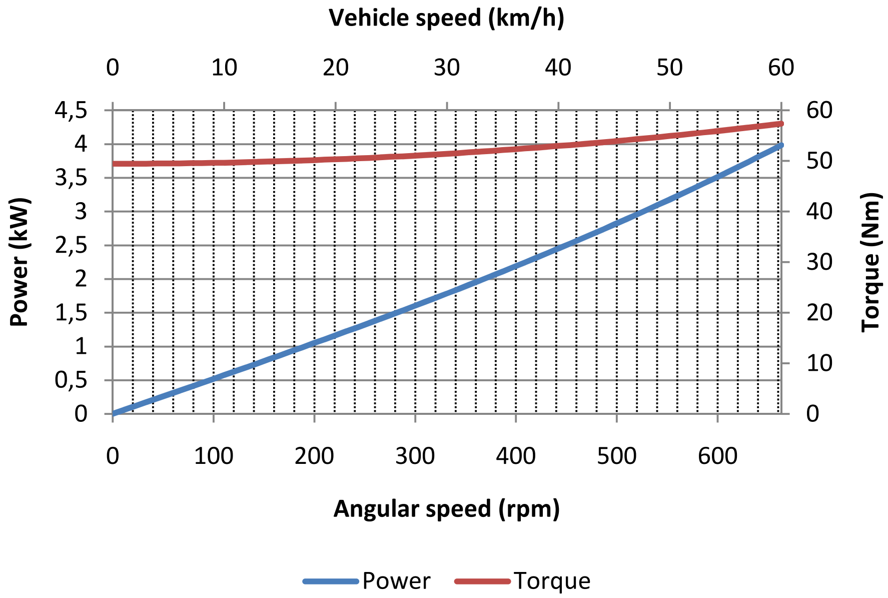


Figure 9.5: Power and Torque requirements for a drive motor on the rail

In the previous Figures it can be seen that (if just two motors deliver all the propelling power on the monorail) the driving motors of the Nano-RUF must be able to deliver approximately and in continuous operation:

Power: 10 kW

Torque: 60 Nm

Angular speed: 1700 rpm

Considering also that the vehicle will require extra power and torque while it accelerates, the peak ratings of the motor have to be accounted for. Normally an electric motor is able to deliver for short periods of time peaks of torque close to 10 times its continuous ratings.

9.3. Driving Range

The driving range of an electric vehicle is the distance that it is able to cover with its charge of battery. It is conditioned by capacity of the batteries, the quantity of batteries and the conditions of the journey. So the driving range will always be variable, depending on the driving conditions.

Driving cycles are used to simulate a typical journey of a vehicle. These drive cycles are represented by the vehicle speeds vs. the operating time while driving.

Simulation of a driving cycle

In this section the Nano-RUF performance will be simulated following a possible driving cycle. By means of this simulation the driving range of the vehicle will be estimated for a certain quantity of batteries.

First of all, a possible driving cycle for the Nano-RUF could be represented in Figure 9.6 in which has been considered an average slope of 3%.

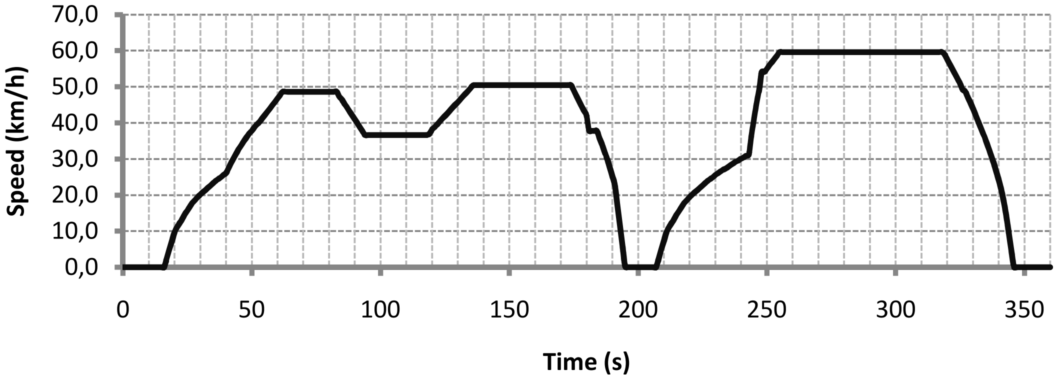


Figure 9.6: Driving cycle used in the simulation

For each second the mechanic power needed to propel the vehicle is equal to the energy required.

$$E = P \cdot t \tag{9.12}$$

$$\text{for t =1 s } \Rightarrow E = P = F_{te} \cdot v \tag{9.13}$$

So, considering the tractive effort of Equation 9.8 and the data of the vehicle (see Section 8.1) the instant energy required in each point of the driving cycle can be calculated.

The efficiencies of the motors with their controllers and the transmission have to be considered. Because of the fact that the vehicle uses direct transmission, the efficiency of the transmission is 100%. For the motors the efficiency is around an 80%, and for the controllers around a 90%.

Thus, the electric power required will be:

$$P_e = \frac{P}{\eta_m \eta_c \eta_t} \tag{9.14}$$

And while the vehicle slows down:

$$P_e = P \ \eta_m \eta_c \eta_t \tag{9.15}$$

In this case the power becomes negative by means of the regenerative braking and the energy will flow from the motors to the batteries.

In addition to the electric power needed to drive, the energy consumption of the electric accessories of the vehicle such as lights, radio, etc need to be considered. This power (P_{ac}) it is estimated as 750 W.

Thus, the total power required from the batteries will be

$$P_{bat} = P_e + P_{ac} \tag{9.16}$$

The addition of the instant power required for each second of the cycle will be the total energy used by the vehicle.

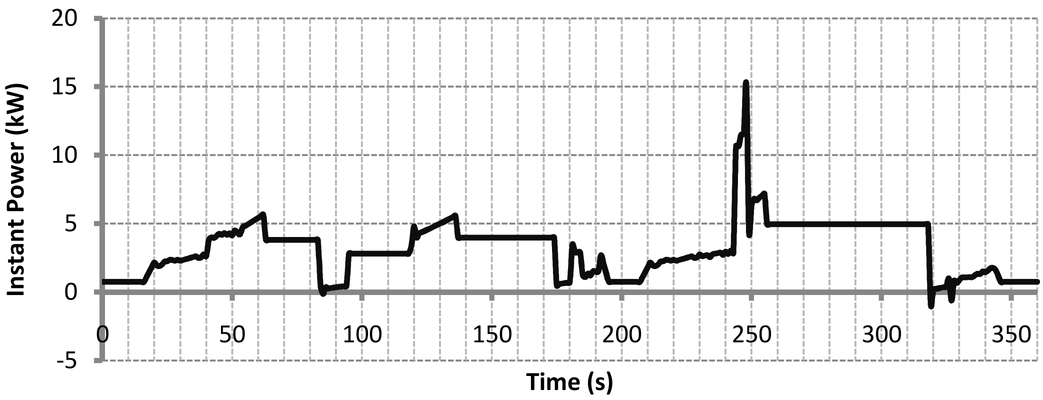


Figure 9.7: Instant power vs. time as a result simulate of the driving cycle

As a result of a journey following the proposed driving cycle with a Nano-RUF:

Duration of the cycle	360 s
Distance travelled	3663,4 m
Total energy consumed	316,35 Wh
Energy per kilometre	86,35 Wh/km
Peak instant power	15,12 kW

Table 9.2: Main results of the simulation of the driving cycle.

Once the energy needed is known the quantity of batteries can be determined.

As explained in Section 7.1.2 high specific energy batteries will be used with the parameters of Table 7.1.

Knowing the specific energy of the type of batteries and the energy required per kilometre of Table 8.7 the distance that can be travelled with a certain weight of batteries can easily be calculated.

$$\text{Distance traveled} = \frac{\text{Energy per km}}{\text{Specific energy of the batteries} \cdot \text{kg of batteries}} \quad (9.17)$$

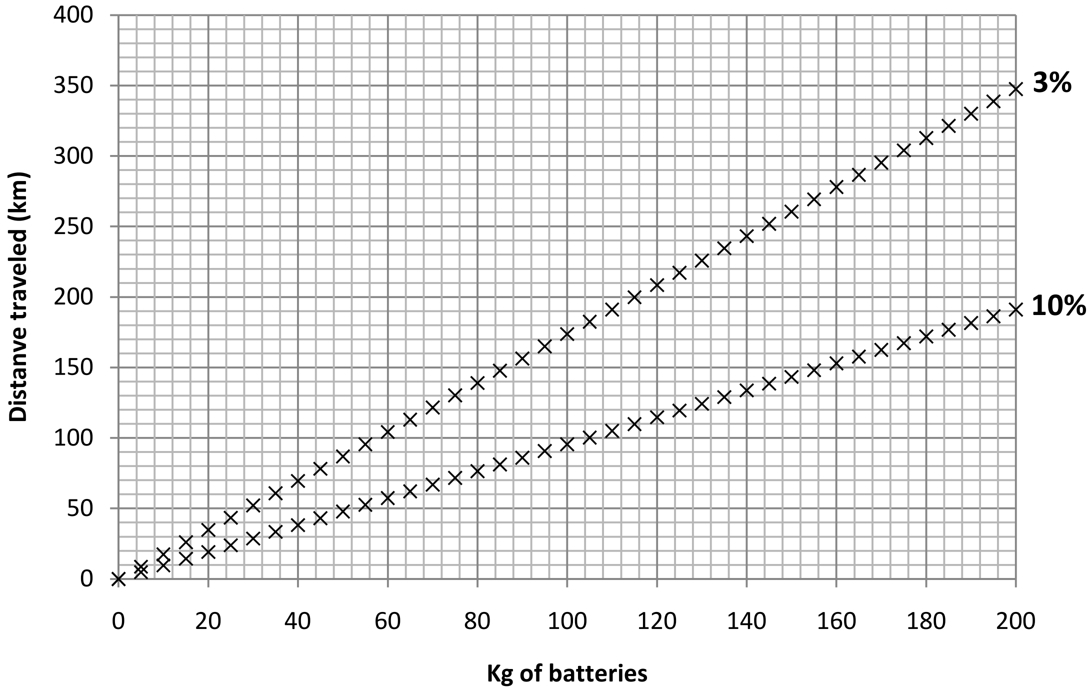


Figure 9.8: Distance travelled vs. kg of batteries for a certain road grade

Driving Range of the Nano-RUF

According to the simulation results, with 60 kg of high specific energy lithium-ion batteries it is possible to drive a Nano-RUF along 50-100 km without recharging the batteries. This seems to be a proper driving range according to the special characteristics of a RUF vehicle.

The initial expected minimum range was of about 10-20 km because the RUF vehicles are able to recharge their batteries while drive on the monorail.

It has also to be considered that the battery technology evolves quickly so the driving range of the vehicle can be improved in the future.

10. Safety and Materials

At first, safety aspects of the Nano-RUF are considered and then materials are discussed, as there is a strong relation between the two subjects.

10.1. Safety Issues

It is not possible to launch a new transportation system and vehicle like the Nano-RUF without considering safety issues. Just in the European Union, more than 40000 lives are lost every year due to road accidents. The costs are estimated to be about 2% of its Gross Domestic Product [EC 2001].

Compared with automobile vehicles, the Nano-RUF has one strong safety advantage. Because of the dual-mode system there are no accidents on the automated monorail except possible system failures. But the probability of them negligible. As a first reference, automated systems like the Metro in Copenhagen can be used. Former projects considered security aspects on the monorail and it was concluded that the automated driving on the monorail is very secure. Therefore, the Nano-RUF could be involved in accidents most likely during the short-distance road journeys. In the past years many security systems were established in new car manufacturing, from pyrotechnic belt pre-tensioning to the addition of several airbags. In the automotive safety industry, two different terms are used: active and passive safety (Figure 10.1).

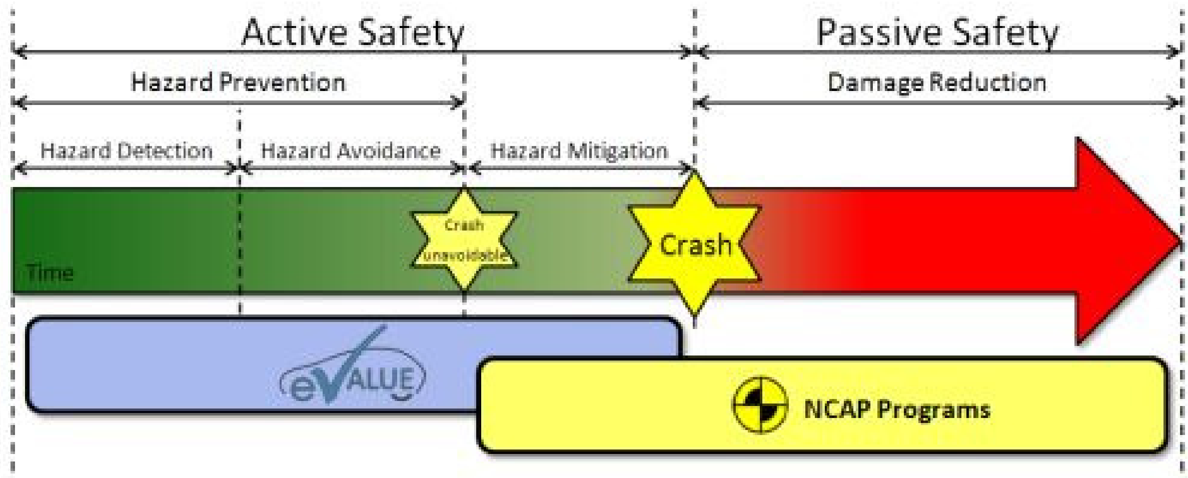


Figure 10.1: Timeline of active and passive safety (Source: http://www.evalue-project.eu/results-motivation.php)

Active safety is described as hazard prevention and hazard mitigation, whereas passive safety is just damage reduction. A clustered road map of active safety systems can be seen in the Appendix 6.1. Passive safety elements are systems which try to reduce the effects of accidents, whereas active safety systems try to avoid a crash and an accident. Due to physical principles there are limits for where passive safety can be developed; therefore the most immediate developments are made with improvements of the active safety. Figure 10.2 shows the development of the active and passive safety in a car.

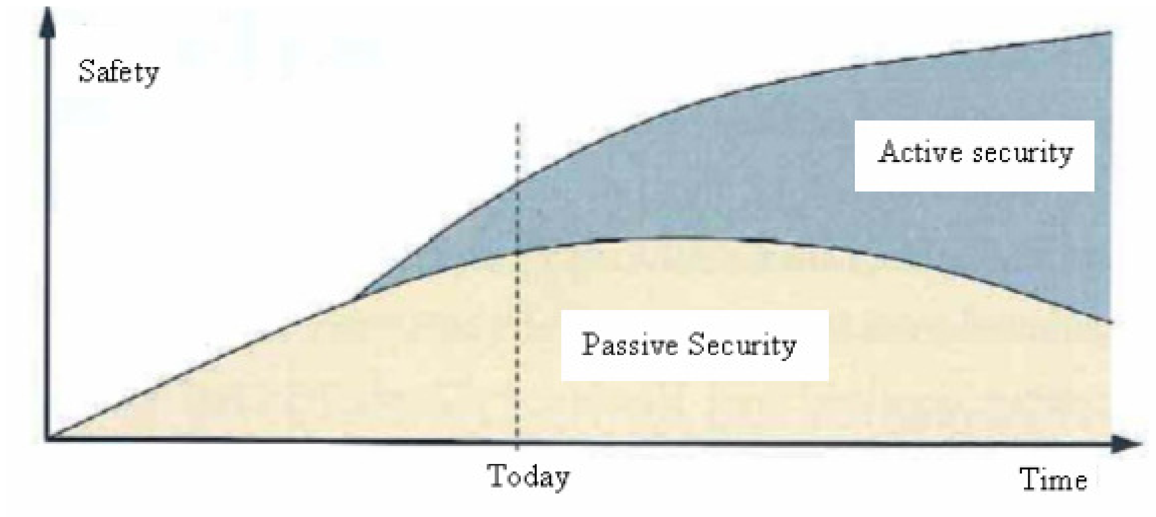


Figure 10.2: Accident prevention – active and passive safety (Source: According to [Koser 2010])

The Nano-RUF with its use of the automated driving system on the monorail is a very effective safety system. Even though the Nano-RUF is small, it is very safe.

10.2. Materials

10.2.1. Automotive Materials

As noted in the previous chapter the Nano-RUF body has to face different challenges compared to a normal car. Because Nano-RUF accidents on a highway with high speed are not possible, the crumple zones, which are designed to absorb the energy from the impact during an accident by controlled deformation, do not have to be as critical as in a normal car. The design is critical because it has a huge impact on the safety aspects of the vehicle (Appendix 6.2).

The following Figure shows the development of the use of steel, plastics, aluminium and magnesium since 1975 for a mid-size saloon car (BMW 3 Series).

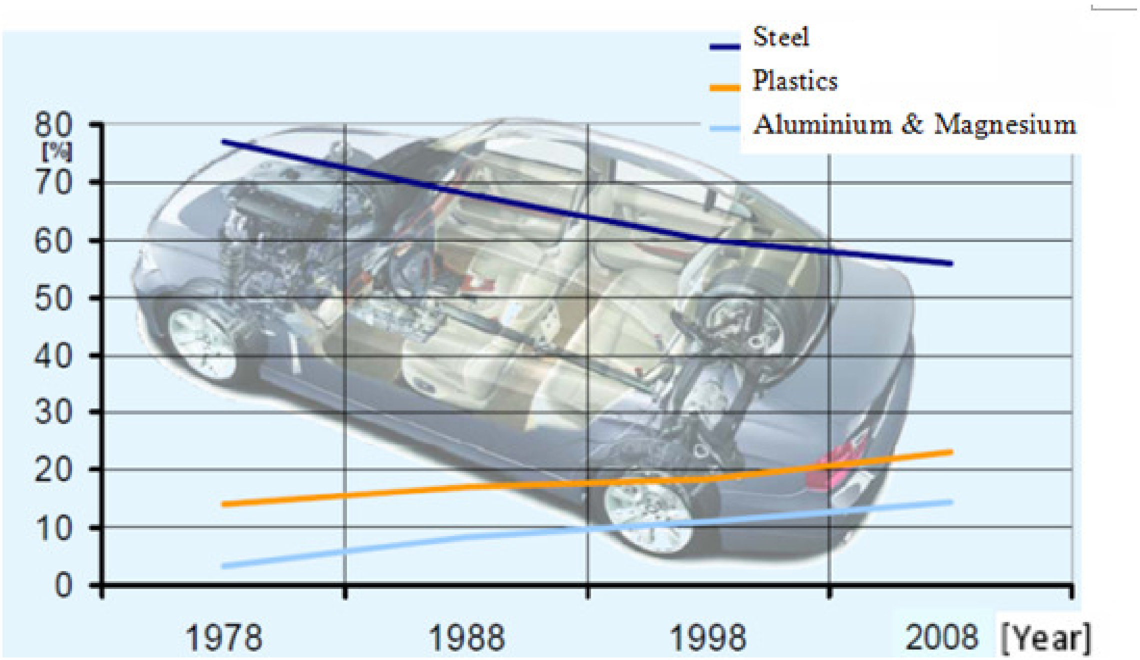


Figure 10.3: Development of use of different materials (Source: [Stauber 2009])

This shows that today in most cars steel is by far the most common used material. But the trend shows an increase in lightweight composite materials. Sport cars use many lightweight materials already. For example, an aluminium body frame from an Audi R8 (the Audi Space Frame is shown in the Appendix 6.3). It is lighter than a steel monocoque, but more expensive in large production numbers.

In the following parts some materials, which are appropriate for the Nano-RUF, are described. Although the group developed the shape and the design of the Nano-RUF, the different parts of the Nano-RUF were not created individually. Therefore as the Nano-RUF and its RUF system parts have not been created in a CAD-software, the following part includes just a description of possible materials without calculations of weight, impact resistance etc. A detailed study of the different materials to create a body frame, like the next Figure visualizes, will have to be done in the future.

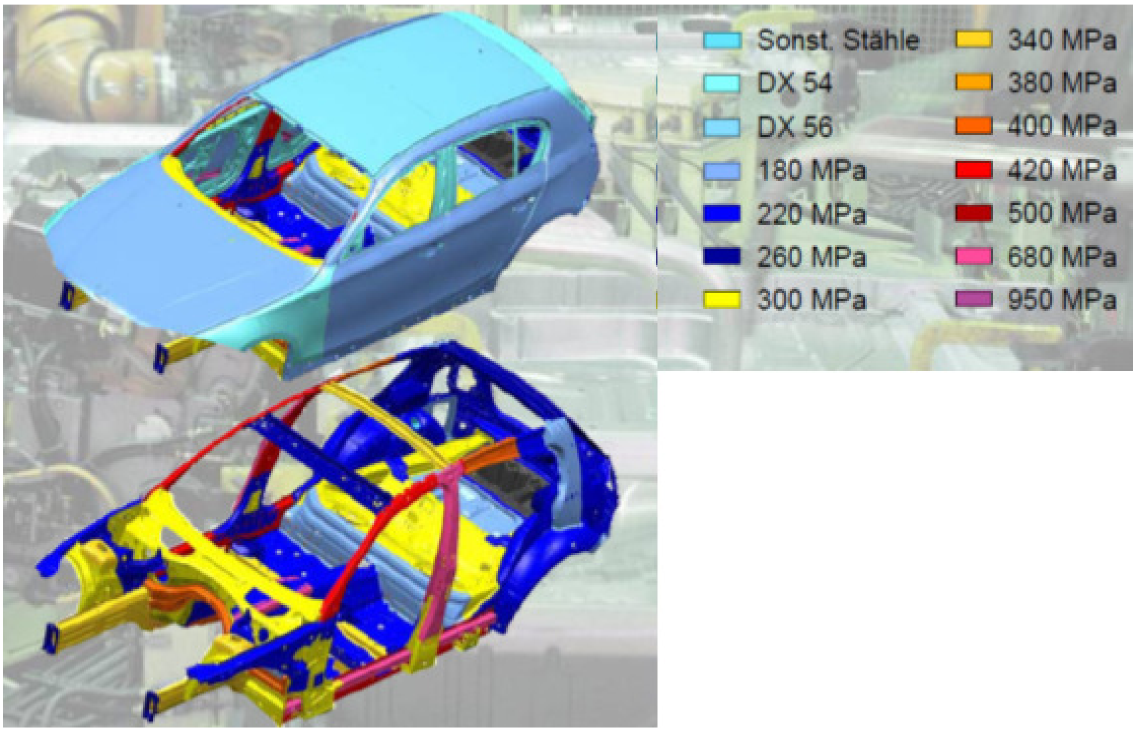


Figure 10.4: Different materials for a car body frame with different yield strengths (Source: [Stauber 2009])

Intensive research about future trends about materials seemed to be most relevant for the group at this stage of the project regarding the time constraints. The group decided to regard two material groups: one based on lightweight materials and another one incorporating renewable materials.

10.2.2. Lightweight Materials

For the Nano-RUF lightweight materials should be used, because they offer a lot of advantages. For example, the lightweight construction influences positively many dynamic aspects, increasing the handling and outright speed. They reduce the efforts to be made at the monorail and the electric motors under all circumstances. The only main disadvantage is that at present time the production and material costs are higher compared to standard materials. But if the whole life cycle is considered, some experts [Powell 2009] believe that it is not more expensive. The weight is a very important issue on all vehicles, there is currently a lot of research in this topic. Therefore the production and material's cost could be reduced due to new developments; only the increasing demand could shift the tendency in the opposite direction.

Most common lightweight materials are aluminium (density of 2.5e3 – 2.9e3 kg/m^3), magnesium (density of 1.74e3 – 1.95e3 kg/m^3), carbon fibre composites (density of 1.5e3 – 1.6e3 kg/m^3) and finally, composites and plastics in general [CES EduPack 2010].

Lightweight construction influences a lot of characteristics like the increase in agility, manoeuvrability and speed while at the same time decreasing energy consumption. Not to forget that a lighter vehicle will also further reduce the vehicle's components size, thus reducing even further the weight, costs and energy needed to power the same vehicle, ever increasing efficiency.

The RUF Company is already working together with the firm 3A Composites GmbH. They sponsor RUF with the product Alucore; an aluminium composite panel consisting of two cover sheets and a honeycomb core of aluminium.

Compared to steel aluminium can provide some advantages such as a lower density, reduced noise, reduced vibration and harshness due to reduced vehicle weight combined with high structural stiffness of aluminium [ATG n.d.]. Another positive aspect of aluminium is that it can absorb nearly twice as much energy as steel. Furthermore, aluminium can be designed to fold predictably during a crash. This means that the design can be focussed in allowing the vehicle absorb all of the crash forces and be safer for the passenger.

Offering equivalent strength, components made from carbon fibre composite (CFRP = carbon fibre-reinforced plastic) weigh up to 50% less than comparable steel components and some are 30% lighter than aluminium components. Due to the high degree of light construction, the composite industry is now evolving from low volume to a high volume mass production. Another reason for this is that within broad limits a suitable combination of fibres and matrix materials via production method can result in different properties, which makes fibre based composites suitable for the most diverse types of component [Vesco 2011].

As of now, carbon fibre has been used solely for some high-end sport cars and race cars. For example the Porsche Carrera GT has a carbon fibre monocoque with carbon-fibre-reinforced plastic sub frames listed [Owen n.d.]. Another example is the McLaren Mercedes SLR with an adhesively bonded carbon fibre sections. In the Appendix 6.4 an image is shown [Santoni 2010].

The first high volume vehicle produced with a passenger cell made from carbon is expected to be the BMW Megacity Vehicle. It should enter the market in 2013. Instead of simply using some carbon components across the roof or the interior, all body panels and the entire structure will be carbon fibre [BMW 2010].

The major barrier from the development of steel towards the production of strong and lightweight materials like carbon fibres has been the high cost. Composites can be moulded into complex shapes, which would allow cars to be made from far less body components. The assembly could be simplified by moulding the parts so they snap together or be glued, instead of being welded or screwed as they are presently. New production and manufacturing technologies are also being developed, for example specific moulding technologies for wrought magnesium alloy.

10.2.3. Renewable Materials

Because of the increase in oil prices and ecological awareness, there has been a revival of natural fibre's use. Natural fibre materials represent high-quality alternatives to synthetic fibres. They are made from plants, animal derivatives and mineral sources which are lightweight, before being manufactured. They offer superior environmental balance and have the possibility to manufacture complex structural elements [Vesco 2011]. A systematic classification, first of natural fibres, followed by a classification of vegetable fibres is shown in the next Figure.

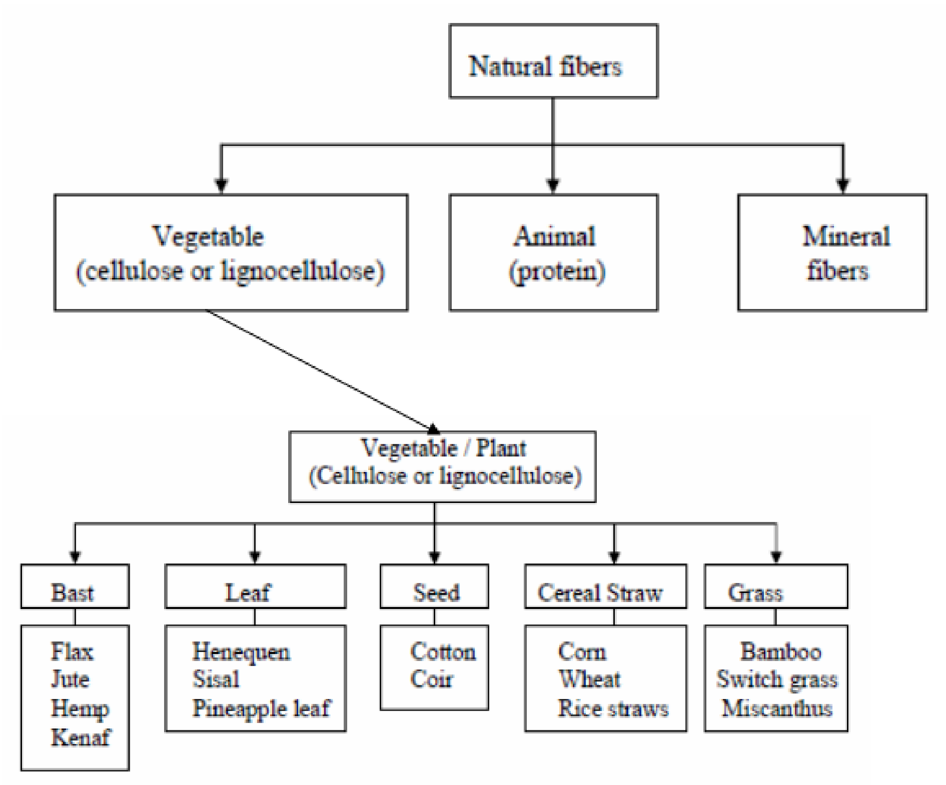


Figure 10.5: Classification of natural fibres and plant fibres (Source: [Josh 2008])

Natural fibre composites can be used for automotive interior components. Their advantages are weight reduction of 10 to 30%, good mechanical properties, no toxic gas emissions when subjected to heat and good overall green properties. For example, the current 3, 5 and 7 series from BMW use about 20 to 24kg of natural fibres in applications like the front fascia and door liners [Ellison & McNaught 2000]. Opel is using a lot of flax to make door coverings [Geiger 2010]. Ford uses soy and bio-based seat cushions and seatbacks. In summary, renewable raw materials such as wood, olive seeds, coconut fibres and flax have an extremely favourable impact on CO2 emissions and energy consumption [BMW n.d.]. Goodyear develops tyres made of renewable rubber as well. They use rubber made from plants. The technology is called Biolsoprene, which is produced by the Genencor division of Danisco. Today most of the tyres are produced using synthetic rubber made of petroleum.

If they could be made out of natural rubber, while natural rubber is itself a bio-based product, the dependency of oil would be reduce thus decreasing its environmental impact [Goodyear 2010].

In summary, renewable raw materials such as wood, olive seeds, coconut fibres and flax have an extremely favourable impact on CO2 emissions and energy consumption [BMW n.d.].

10.2.4. Highly Innovative Technologies

- Composite materials able to store electrical energy

A prototype material which can store and discharge electrical energy, but is lightweight and tough enough to be used in cars is being developed by a collaboration between researchers from Imperial College London and European partners, with help from Volvo car manufacturer. Parts of a car's body could double up as its battery. This could lead, if it is used in vehicles, to lighter, more compact and more energy efficient vehicles and would have the potential for big changes. The material is a composite made of carbon fibres and a polymer resin. It would store and discharge large amounts of energy much quicker than conventional batteries [Smith 2010].

- Nanotechnology

Nanotechnology is a branch of engineering that deals with design using very small particles. It is used to describe the science and technology related to the control and manipulation of matter and devices on a scale less than 100 nm in dimension [Ahmed 2009]. Applications for the Nano-RUF could be the production of mirrors or side panels out of nano particles. Being so, they are able to filter the rays of sun, smoke and other pollutants in the atmosphere. Another possibility is the use to create a lighter chassis or increase the stiffness. Antireflection coating based on multiple nano layers on glass (trade name Schott Conturan) is used for different instruments by car manufacturers Audi and by DaimlerChrysler. Furthermore, Figure 10.6 shows potential areas where nanotechnology can be applied in automotive areas and consequently in the Nano-RUF.

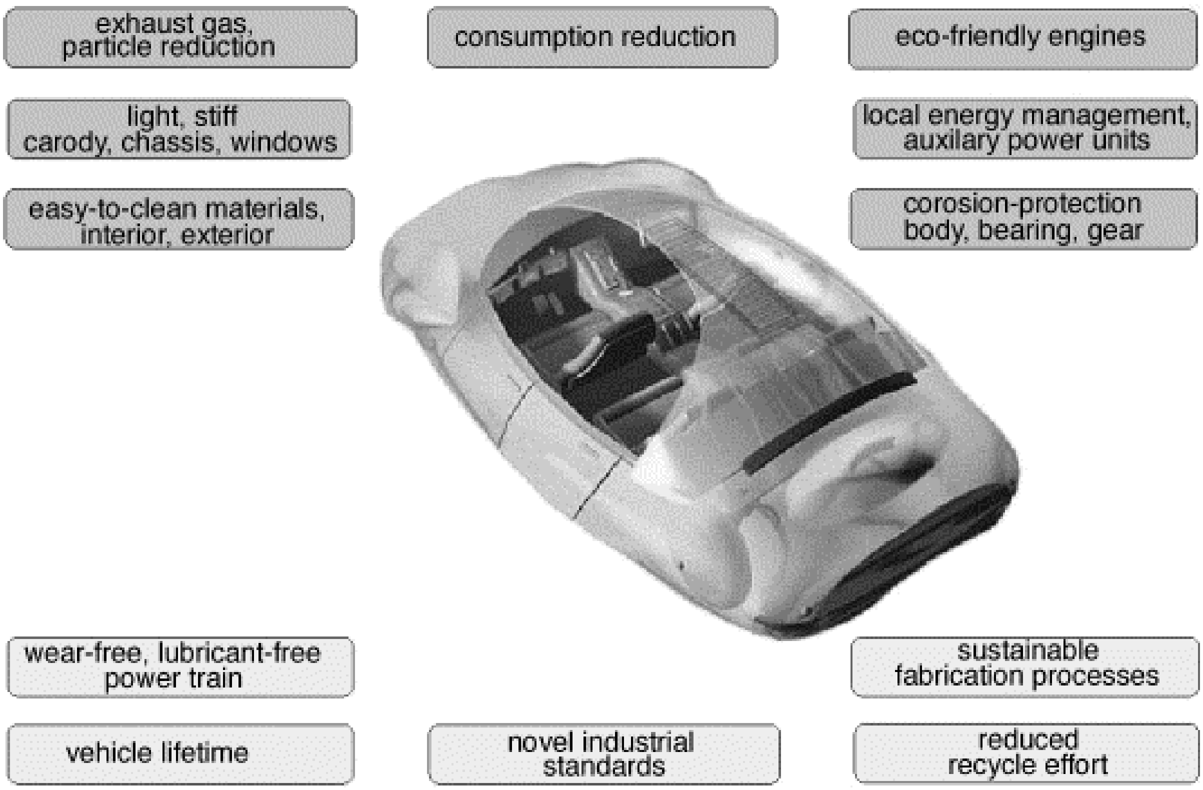


Figure 10.6: Potential areas where nanotechnology can contribute to satisfy society demands in the automotive industry (Source: [Presting & König 2003])

10.2.5. Recycling

Developing a precise design of all the parts of the Nano-RUF with recycling in mind should be a consideration. For instance, large components that are easy to disassemble and separate. The Figure below shows the European Recycling quotes. These are mandatory; therefore the Nano-RUF must also fulfil these aspects.

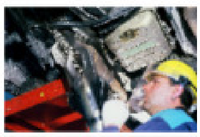
	2006	2015	
reutilisation and material recycling	> 80 %	> 85 %	
termal utilisation	5 %	< 10 %	
energy recovery	> 85 %	> 95 %	
landfill site	< 15 %	< 5 %	

Figure 10.7: Car recycling - utilization rate (Source: [Stauber 2009])

To fulfil the sustainable and green concept of the Nano-RUF it should be aimed to have the highest rate of reutilisation and material recycling as possible.

Aluminium is a very good material to recycle. It saves nearly 95% of the greenhouse gas emissions associated with primary aluminium production and requires only about 5% of the energy. Since about 60% of aluminium that is used on today's vehicles is sourced from recycled metal this shows a clear advantage [ATG n.d.].

10.3. Summary

There is not one main material chosen for the Nano-RUF. Different parts require different solutions. A careful mix from a range of materials is essential. Even with their higher prices, lightweight materials should be considered and used whenever possible. Composite lightweight materials are the preferred choice for the body panels. For the chassis and component assemblies an ultra light material mix made from an alloy of aluminium and magnesium. Where necessary, some high-strength steels could be used. As mentioned before, the following step is to develop the different parts of the Nano-RUF such as body, chassis, etc. And therefore choose specific materials for these. CES EduPack 2010 In Level 3 can be a very good tool for this matter. At this stage the group used mainly basic datasheets with the different properties.

For different interior and exterior parts, renewable material applications are a good solution. The ideal way for the Nano-RUF is to be made from fewer oil derived products and become a truly green, zero emission vehicle. Even if retail price is higher for the lightweight materials, a detailed life cycle cost analysis has to be taken into account.

Furthermore, there is a strong relationship between the materials and the safety of the Nano-RUF. The dual mode entails that during the automated monorail mode the Nano-RUF is ultimately safe, even when taking into consideration the high speeds attained. On the road mode there will be low speed driving which should reduce the severity of potential accidents. Therefore the safety requirements can be significantly less than in mainstream road vehicles. It would be recommended to propose to governments specific safety regulations for Nano-RUFs.

According to a survey done by the Rocky Mountain Institute, the majority preferred to be in a bigger car rather than in a lighter and smaller car in case of an accident (Appendix 6.5). Finally, it is important to be able to communicate the safety of the Nano-RUF. Even if safety is tested and guaranteed, it must be ensured that customers accept that an extremely lightweight vehicle is a safe option.

11. Models and Animation Process

11.1. Introduction

To design the 3D model of the Nano-RUF, sketches were needed. See Chapter 7 for concept Sketches. The final sketch and the 2D engineering drawings were used to draw the complete 3D model. This chapter describes the complete 3D drawing process of the Nano-RUF. With this model it was possible to make an animation. This gave the opportunity to give a clear view of the process that the Nano-RUF is going through. A rough explanation how the animation was built up will also be described in this chapter.

11.2. Nano-RUF Drawing

To draw the Nano-RUF three different drawing programs were used. The first one was Autodesk Alias. This program can create free form shapes. This is exactly what was needed to draw this vehicle. 2D sketches as a reference were very useful to begin. As can be seen on the Figure below these 2D sketches were imported and set up as a background image. Then the drawing of the curves could be started.

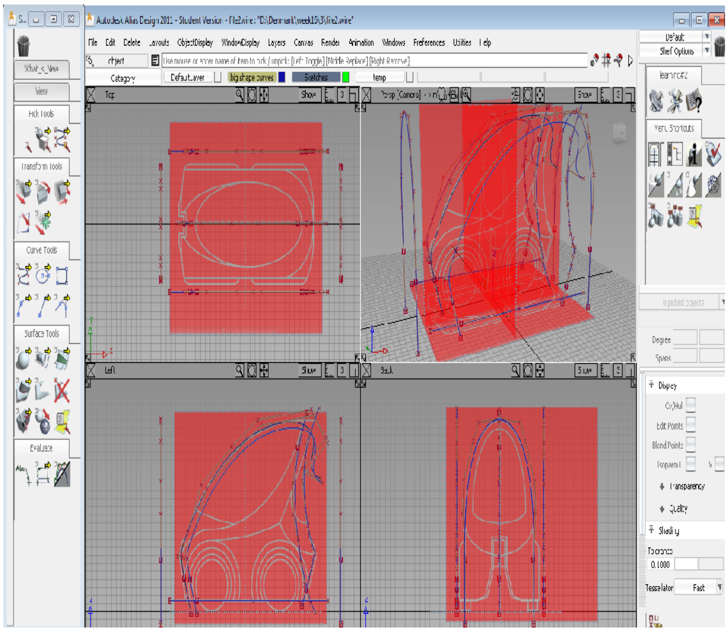


Figure 11.1: Autodesk Alias, curves

After this first step the rough shape could be built up. The steps to realize the shapes can be seen in Figures 11-2, 11-3 and 11-4 and are described in Appendix 7.

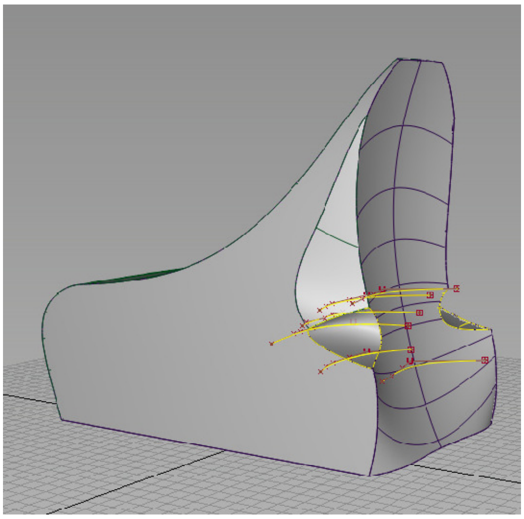


Figure 11.2: Detailed shape

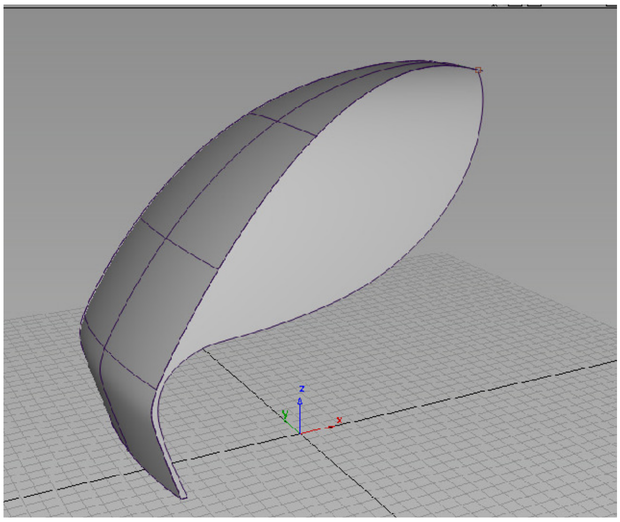


Figure 11.3: Shape door

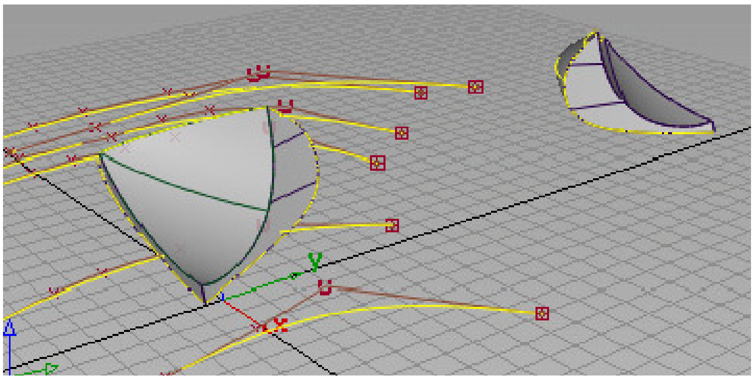


Figure 11.4: Back lights

These drawings were used to add more details. The next program used, also a 3D drawing program, was Autodesk Inventor. First the cockpit will be described.

To create the shape of the cockpit (Figure 11.5) several steps were needed. The first one was adding the section for the monorail. Secondly a shell was used. This function created a wall thickness to the full shape. Afterwards the circles for the wheels were cut out the shape of the cockpit. A back window was needed so this shape was also cut out. To finish, some fillets were added.

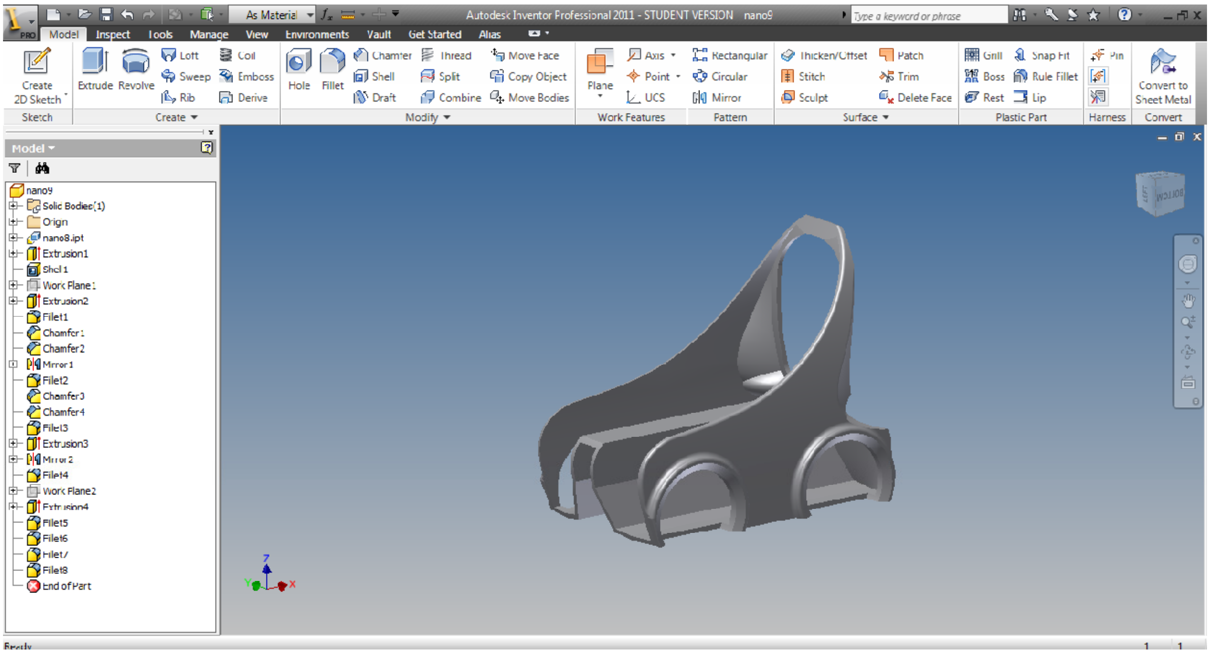


Figure 11.5: Final shape cockpit

The next shape to be described is the door. Because the door consists of two materials, the front window and the rest of the shape, these parts needed to be separated. This was the first step. The second step was to add a wall thickness to the front window. This was done with the shell function. And so the shape for the window was finished. The second part of the door was the next step. First of all the section for the monorail was added. This part also needed a wall thickness. Additionally the vehicle has front lights and side mirrors. The result can be seen below.

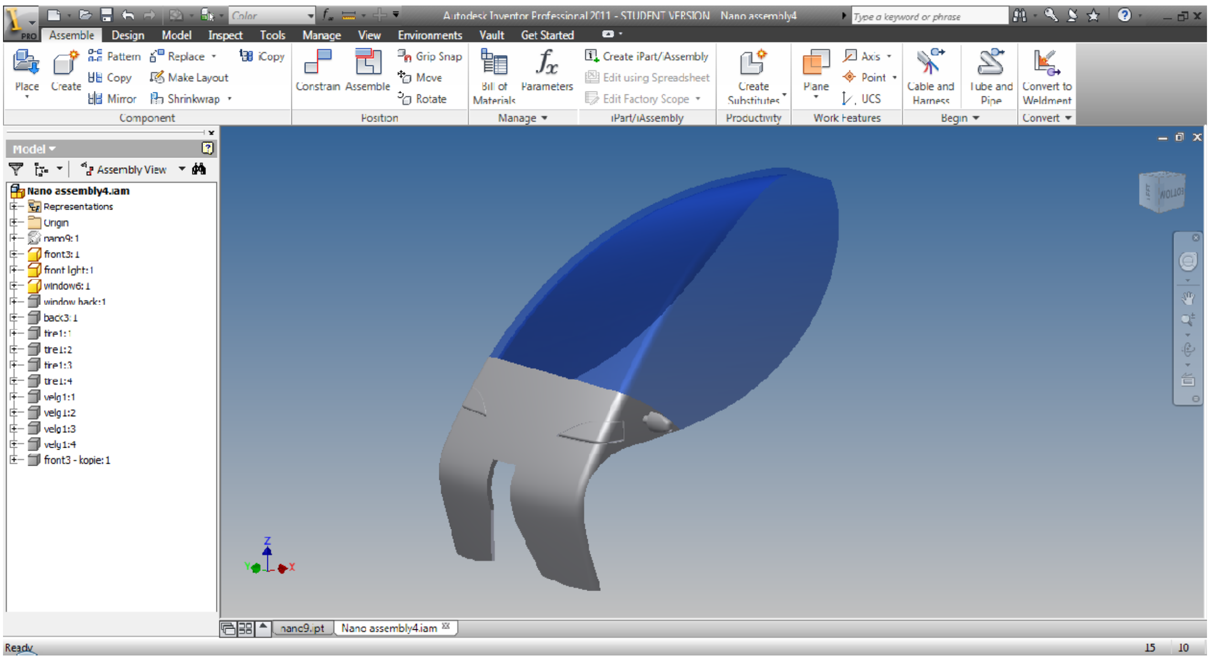


Figure 11.6: Final shape door

The last parts needed were the wheels. These have a basic shape and could be drawn in Autodesk Inventor (Figure 11-7).

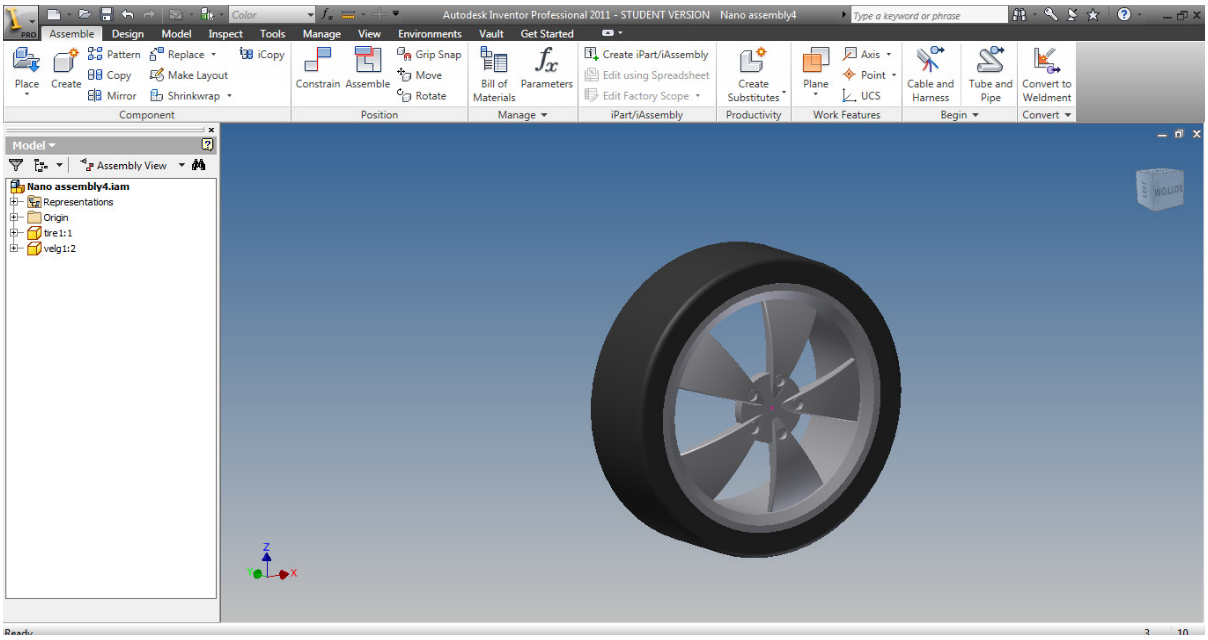


Figure 11.7: Wheel

Now that all the parts of the vehicle were constructed, the assembly could be made. The cockpit was the first shape and formed the base of the assembly. The other parts were assembled one after the other. The result is shown in Figure 11.8.

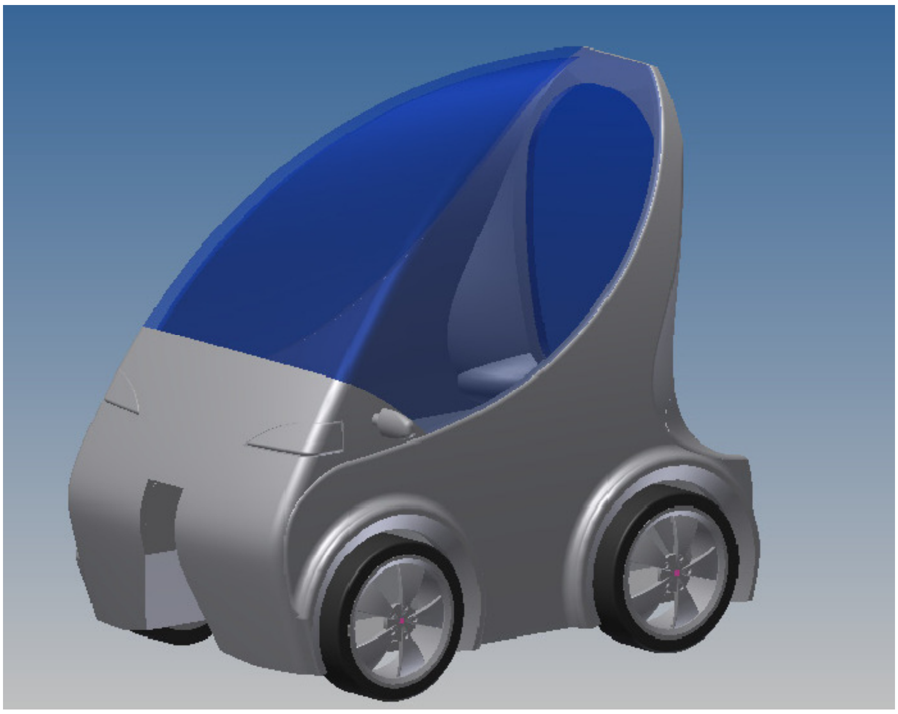


Figure 11.8: Assembly Nano-RUF

The drawing of the Nano-RUF was finished. It was time to make images depicting the vehicle. This was done in 3D Studio Max. By using different materials for the different parts, the vehicle looked very realistic. Using different lights, it was possible to create realistic shadows and reflections. The final result of the Nano-RUF is shown in Figure 11.9.

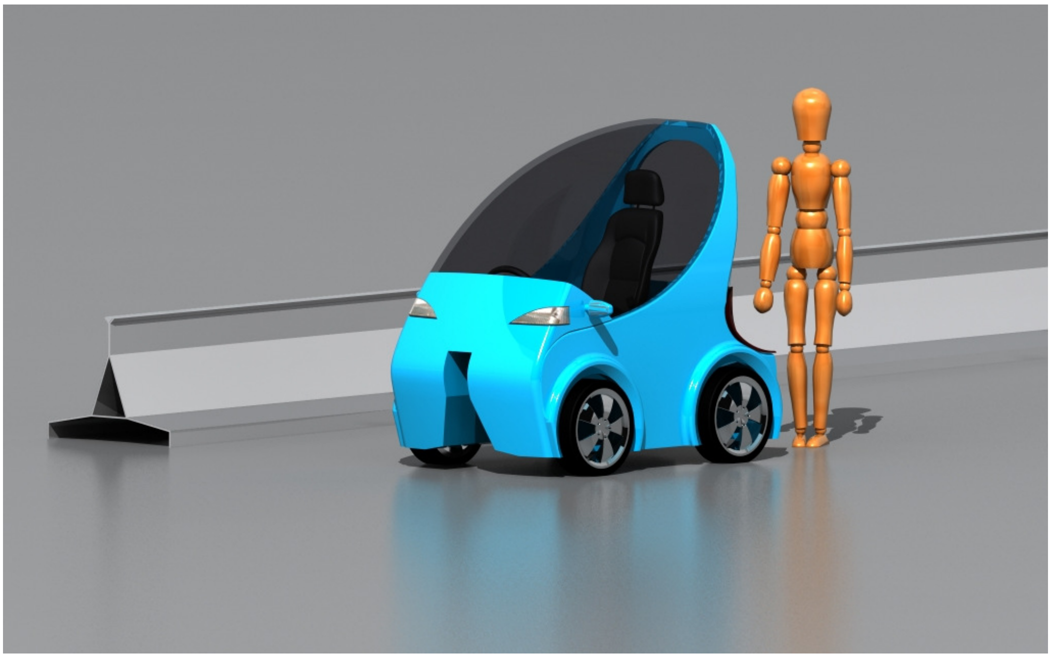


Figure 11.9: Final result

11.3. Animation

11.3.1. Introduction

In this chapter there will be a description of how the animation was made, e.g. the different programs that were used. Appendix 7 shows some technical information about how the animation was built up. The complete animation to describe the whole process consisted of seven different parts.

- Start
- Leave home
- Enter the monorail
- Drive on the monorail
- Leave the monorail
- Arrive at your destination
- Ending

For each of these seven parts a different scene needed to be made.

11.3.2. Start

The introduction starts with keywords for Nano-RUF. From the first moment it needs to be clear what the Nano-RUF is about. This is followed by an overall view of the vehicle so that all the sides of the vehicle can be seen.

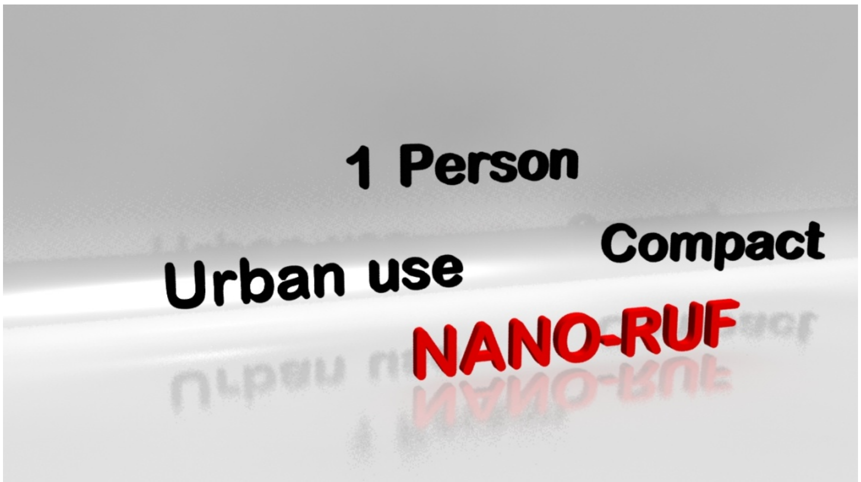


Figure 11.10: Start animation

The Nano-RUF vehicle used in the animation is the drawing described in Chapter 11.1. The wooden person was set up to give a reference to the dimensions of the Nano-RUF. This model is a download from a website (Source: http://artist-3d.com/free_3d_models/dnm/model_disp.php?uid=636&count=count).

Figure 11.11: Nano-RUF model

11.3.3. Leave Home

This scene is a view of a street with houses. The houses are drawn in Autodesk inventor. In Appendix 7 screenshots of the drawings of the houses can be seen.

The rest of the scene was made in 3D Studio Max. To make the scene as realistic as possible, some materials and bitmaps *(an image used as a material)* were added to different parts in the scene, e.g. a bitmap was added to the roof and the walls of the house, windows were given the material of glass, etc. To become a realistic view during the daytime, two standard target spot lights were added as can be seen in the Figure below, e.g. shadows. The first one is to create the shadow. The second one is to make the surrounding more clear.

Figure 11.12: Leave home

11.3.4. Enter the Monorail

To make the second scene, the junction needed to be drawn. This was done in Autodesk Inventor. The junction consists of a part where the RUF drives up to enter the monorail, or drives down to leave the monorail. It consists of monorail inclines that connect to the main monorail. More detailed views of the junction can be found in Appendix 7.

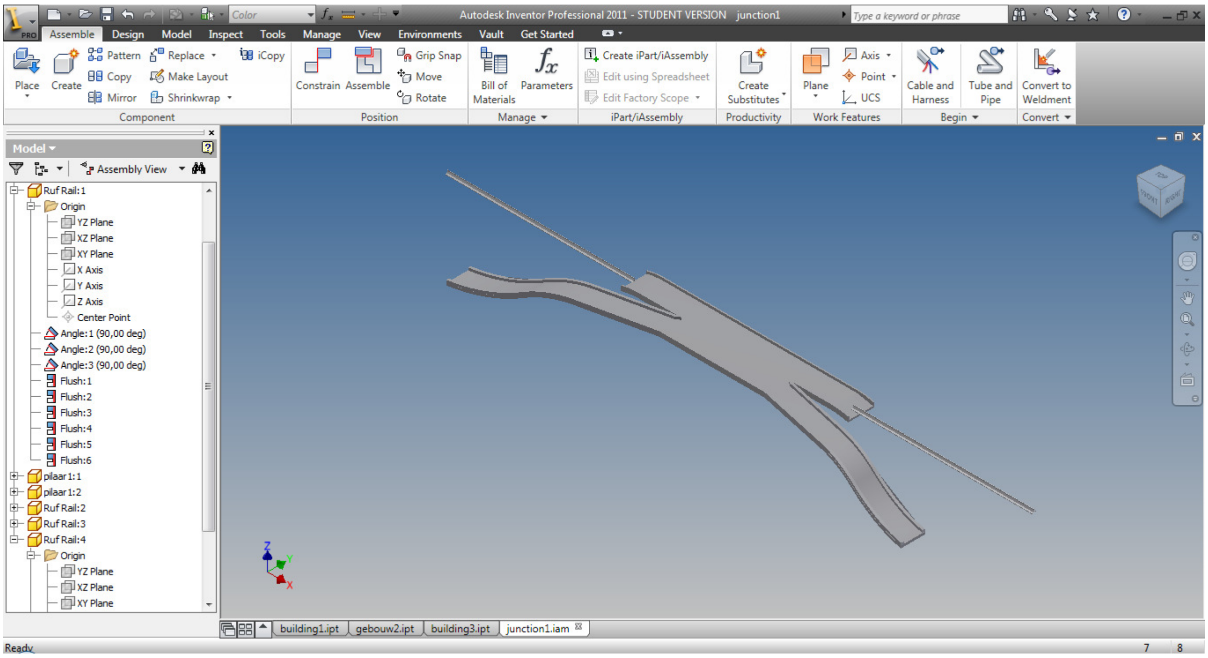


Figure 11.13: Junction to the monorail

Besides the junction, the drawing of the monorail for this scene was also needed. The dimensions of the rail already exist so it did not need to be designed. But the rail needed to be drawn. First a 2D sketch was made in AutoCAD (Figure 11.14). This drawing was used to make the 3D shape of the rail.

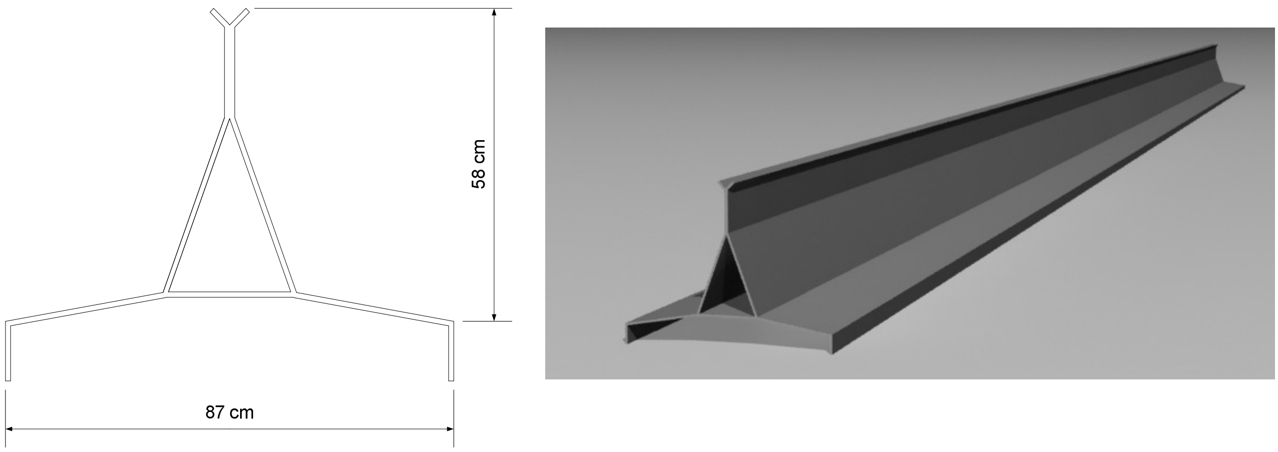


Figure 11.14: Monorail

After these drawings were obtained, the complete scene could be made. The background is just grass and road. The pillars under the monorail are located 20 meters apart. Standard target spot lights were also used in this scene to make it look more realistic.

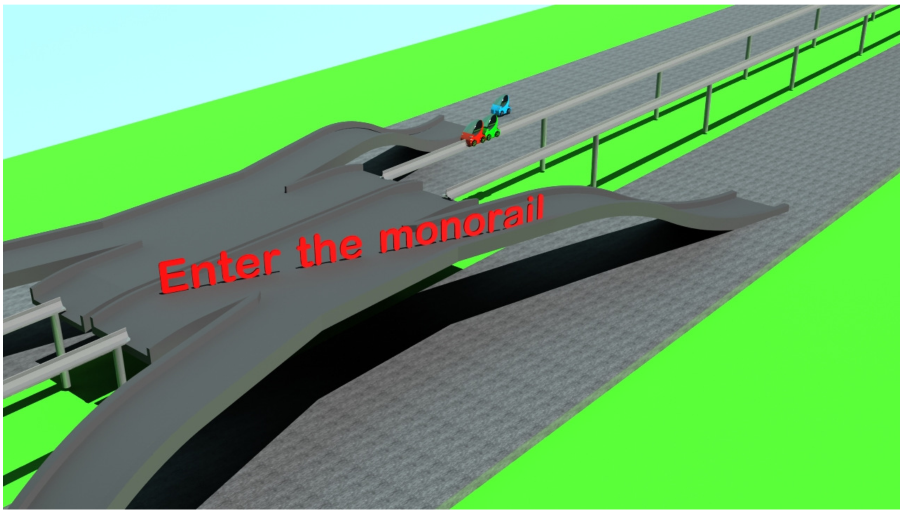


Figure 11.15: Enter the monorail

11.3.5. Drive on the Monorail

The next movie is about the Nano-RUF driving on the monorail. It can be seen in Figure 11.16 how a short train of RUF vehicles drive on the rail. For this scene the drawing of the monorail was needed again. The background in this scene was designed in 3D Studio Max. Again 2 standard target lights were used to create a realistic view.

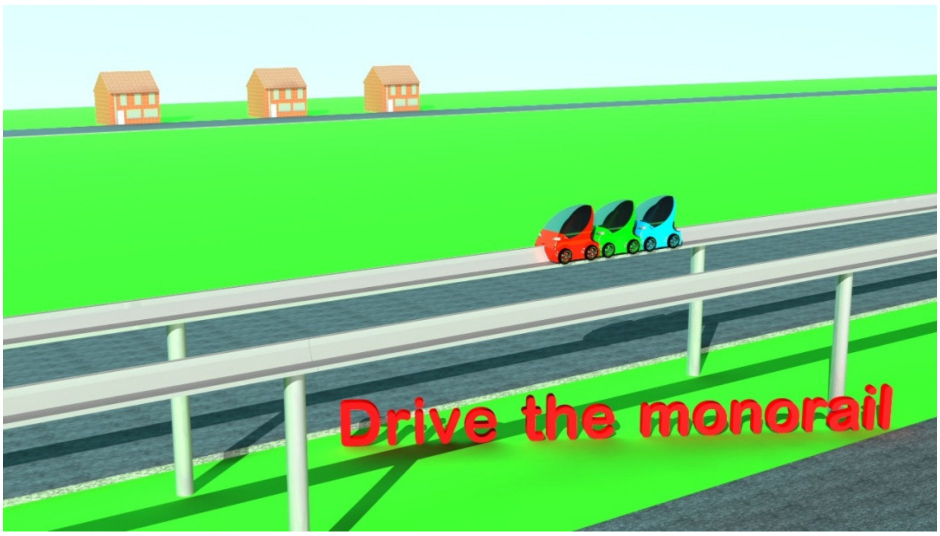


Figure 11.16: Drive the monorail

11.3.6. Leave the Monorail

The previous scene “Adapt to the monorail” could be used for the next animation. But the camera view will be different.

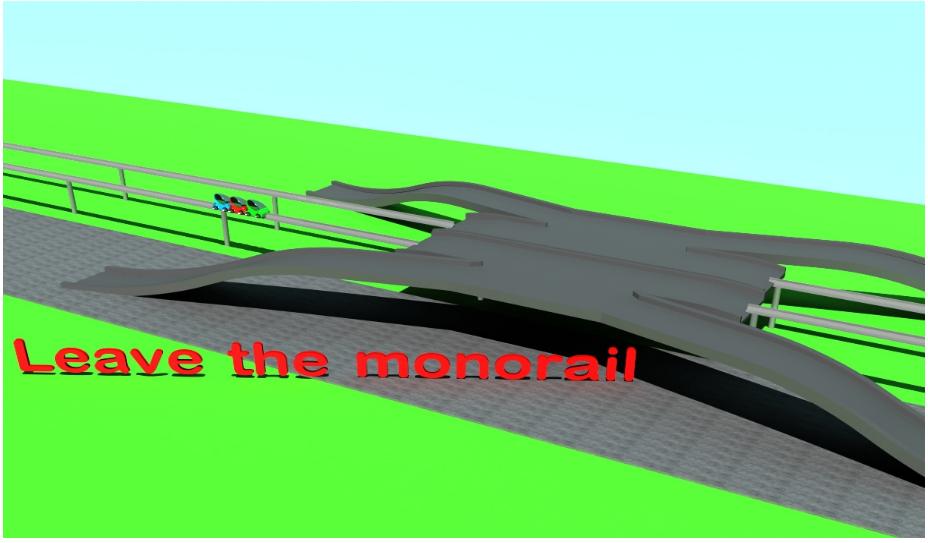


Figure 11.17: Leave the monorail

11.3.7. Arrive at your Destination

Because a lot of people drive alone to their work, this last scene about arriving at your destination shows a view of office buildings. The buildings were again drawn in Autodesk Inventor. In Appendix 7 the result of the drawings can be seen.

The rest of the background, e.g. the parking places, the road, the street lights etc, was created in 3D Studio Max. To make the scene realistic, some materials to the buildings were added, e.g. the windows are glass. Again two standard target lights were used.

Figure 11.18: Arrive at your destination

11.3.8. Ending

The final part of the animation gives the names of the participants of the project.

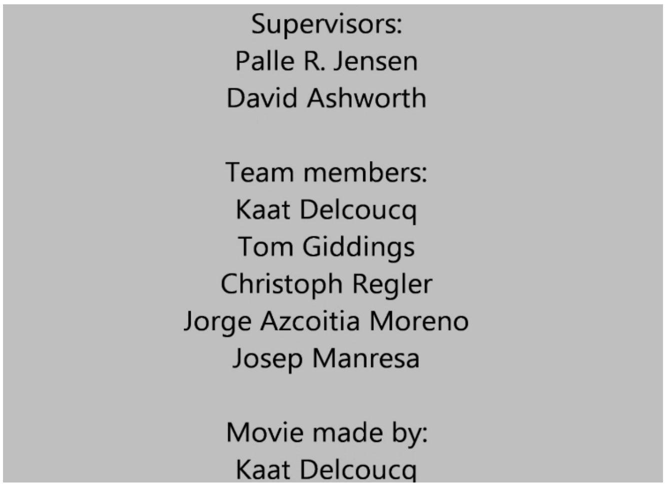


Figure 11.19: End Credits

11.4. Summary

The chapter described how the Nano-RUF was drawn and how the animation was made. The complete animation has a duration of 1 minute and 12 seconds. The animation starts with keywords and a general view of the car. Afterwards it can be seen how the vehicle drives on the road; how the vehicle enters to the monorail and then drives on the monorail; how the Nano-RUF leaves the monorail and finally how the Nano-RUF arrives at its destination. After watching the animation, the process that the Nano-RUF is going through should be clear.

12. Nano-RUF Features

After the description of the design stage, the technical parts results of the Nano-RUF can be summarized.

The Nano-RUF is the smallest member of the RUF family. It offers both the advantages of the RUF system and of a modern urban vehicle. This means a dynamic, fun, original and efficient vehicle which is perfectly suited for city journeys and also to long distance through the RUF monorail.

Nano-RUF is the solution for people commuting in congested areas with economic and green-thinking priorities. Its compact size is a key factor for being able to manoeuvre in tight spaces common in today's congested traffic.

Speaking of space, the user will not have to worry about having to leave a gap to open the door after parking. The Nano-RUF has an innovative solution to parking. Its exclusive upwards front opening door-canopy system enables the user to enter and exit straight to the sidewalk, making it more comfortable and safer than any other vehicle.

Furthermore, the design was conceived to make the Nano-RUF as wide as a parking's width space, where as much as three Nano-RUFs can be parked facing the sidewalk in the space usually taken by a family saloon.

Based on a minimalistic concept, its lightweight construction gives way to very low energy consumption and a higher efficiency than any petrol-based vehicle on sale.

Figure 12.1: Nano-RUF design

Driving enjoyment has also been a concern when developing the Nano-RUF. Comfortable suspension that controls the cars movements give the driver a feel of precision and fun never seen in a city car.

Height is usually an indicator of high centre of gravity in other vehicles, but since the Nano-RUF concentrates most of its weight in the floor, where the batteries are situated, (the most dense and heaviest component). It is reasonably low for its height, enabling for good driving dynamics and response to the controls.

The drive train is fully controlled by wire. From the brake and accelerator pedals to the steering every controller is designed to be adjustable to the user's preferences and response, agility and comfort. This also reduces the maintenance cost from regular systems and improves the reliability by a considerable margin.

Using electric motors powered by lithium batteries, the Nano-RUF is as environmentally friendly as it is economical to run simply by plugging and recharging it at home with a regular 220V 16A household electrical supply or by using the monorail system to recharge the batteries while travelling.

The monorail concept the RUF range introduces will change the way in which people commute both in cities and in long distance trips. Every 5km you will be able to join the monorail system by driving into an elevated platform, free of congestion, as its design makes it much more efficient than regular highway driving. By selecting your destination, either when starting the journey or when reaching the monorail platform, your Nano-RUF will drive for you until it reaches your exiting platform, which will be at less than 5km of your final destination.

In this trip on the monorail the user may join other Nano-RUF users which will create a train, reducing air resistance and thus, increasing the speed but crucially reducing energy consumption. The more vehicles that are coupled together, the less energy required to power each individual vehicle.

Figure 12.2: Nano-RUF train

The vehicles performance is a direct transmission drive train composed of two in-wheel motors that are able to deliver 20 kW (27hp) which are enough to propel the Nano-RUF up to 150 km/h while it is driving on the monorail.

For the use on the road, speed is limited to 60 km/h to comply with moped regulations and be accessible to drivers with a moped license.

The driving range is close to 60km on one full charge, thanks to a high performance lithium-ion battery. There is also the function that recovers energy and recharges the batteries on the monorail which gives the Nano-RUF a high flexibility and an even higher efficiency.

Safety has been a major factor when designing the chassis of the Nano-RUF. Using FIA certification for the tubular frame that creates a safety cell around the driver, passive safety is unrivalled. Although the stopping power from the regenerative motors stops the car in most of the situations, a further electrically operated disc-brake with the latest generation of ABS has been added for emergency stops.

Dimensions: 1,80 x 1,20 x 2 m (H x W x L)
Weight: 350 kg
Rated Power: 20 kW
Max speed: 60 km/h (road driving) – 150 km/h (monorail)
Driving Range: 60 km
Charging voltage: 230 V 50Hz

Table 12.1: Summary of specifications

13. Conclusion

This report is the complete work of Group ones task to design and develop the Nano-RUF vehicle. It describes the research, results and analysis the group made throughout the project. Firstly the group made some preliminary research into the RUF system and its process. Once an understanding was reached an aim was set for the group to achieve. This was to dimension and describe a compact personal mobility vehicle for urban use that is adaptable for the RUF rail system. Then drawing upon their own knowledge and external resources they formulated methods to achieve this goal. The group tried to solve problems in a structured and systematic way. Such methods were Gantt Charts, Morphological Charts and the Responsibility Matrix. These helped to split up work tasks so each group member could work efficiently on their strongest area of study, thus producing the best possible result.

The group intended to follow user-centered design and formulated their own research by producing questionnaires and surveys. This primary evidence showed that there was a large target market for the Nano-RUF as a system, and a vehicle. Evaluating the results helped to set some of the design parameters and establish the critical needs of the user. It gave the project the focus and a greater understanding of what the Nano-RUF truly had to become.

It is clear that a Business Plan could help the Nano-RUF's implementation as it would enable it to get more funding. It is a useful tool to show the technology to all kinds of potential investors and as well a systematic way to describe the Nano-RUF. It was critical to make estimations about the future and regarding how the Nano-RUF could benefit from changes such as rising oil prices or environmental legislations. This helped develop the beginning of the Nano-RUF from an idea to a concept vehicle.

Throughout the design phase it was always important to keep the user in mind and the results that were collected from earlier research. Various technical solutions were explored in sketch work using similar case studies of electric vehicles to base the new designs. As the design phase continued difficulties were experienced with incorporating the radical RUF system into a small lightweight vehicle. However this was over come as more and more electrical solutions were investigated and explored through task analysis.

As the RUF system is an electrical system it was necessary for the Nano-RUF to use it as its power source. This meant that most of the components could be electrical instead of mechanical. This also meant that newer technology could be incorporated into the design, using smaller components that would effectively reduce the size and weight of the overall concept. Making it far more efficient than internal combustion engines. So it was essential that the technical aspects of the vehicle could be estimated using scientific and mathematical formulae.

As a final concept was reached it was important that technical drawings and data could be recorded. These drawings showed the concept as an engineering structure rather than an idea or a concept sketch. It also lead to design of critical components such as the internal chassis structure, suspension system and the clamping wheel construction. These dimensionally accurate drawings could then be scaled down to produce foam models and 3D renders.

The final concept is displayed in a short video. The video demonstrates how the Nano-RUF functions in its environment. It includes how the RUF reacts on the rail environment with other such vehicles.

For further work for future teams it would be interesting to develop a final materials selection for a working prototype or by creating an accurate 3D CAD model that could be exported for computer aided manufacture. This should give a real hint of the potential of the vehicle in real situations. Some of the proposals have already been discussed in this report. Another solution to develop would be the coupling mechanism to the monorail, how to make it smoother for the users and to design a suitable method for vehicles to connect into a train format as closely as possible.

In conclusion the group has successfully designed a Nano-RUF vehicle that is compact, energy efficient and meets the design criteria that was set to provide for the user.

References:

[Ahmed 2009] Ahmed, W.; Jackson, M.J.; Hassan, I.U.: Nanotechnology to Nonmanufacturing, 2009, viewed 24 May 2011, http://www.sciencedirect.com/science/article/pii/B9780815515838000016

[Andrusko 2010] Andrusko, A.: Dual Mode Transportation. A Revolution in Motion, American Institute of Certified Planners, 2010, viewed 24 May 2011, http://www.planning.org/thenewplanner/2010/spr/dualmode.htm

[Anthony et al. 2008] Anthony, S.D.; Altman, E.J.; Johnson, M.W.; Sinfield, J.V.: The Innovator's Guide to Growth: Putting Disruptive Innovation to Work. Boston: Harvard Business School Publishing, 2008.

[ATG n.d.] Aluminium Transportation Group: Auto and Light Truck, viewed 24 May 2011, http://aluminumintransportation.org/main/auto-light-truck/auto-light-truck

[Blackburn 2011] Blackburn, R.: Cars are the biggest losers, 2011, viewed 24 Mau 2011, http://news.drive.com.au/drive/motor-news/cars-are-the-biggest-losers-20110408-1d6zp.html

[BMW 2010] BMW in the News: BMW Teases Megacity EV with Carbon Fibre Structure, 2010, viewed 24 May 2011, http://www.bmwinthenews.com/bmw-teases-megacity-ev-with-carbon-fibre-structure/

[BMW n.d.] BMW: Renewable Raw Materials - the trend of innovation in BMW, viewed May 24 2011, www.oioidesign.com/.../bmw/RENEWABLE%20RAW%20MATERIALS.doc

[Business.gov.au 2011] Business Plan guides & templates, viewed 24 May 2011,

http://www.business.gov.au/Howtoguides/Thinkingofstartingabusiness/Whatplanningtoolscanhelpme/Pages/Businessplanguidesandtemplates.aspx

[Chen et al. 2009] Chen, X.-P.; Yao, X.; Kotha, S.: Entrepreneur passion and preparedness in business plan presentations. Academy of Management Journal, 02/2009, Vol. 52, Issue 1, p. 199-214.

[CES EduPack 2010] CES EduPack: Materials, Granta, 2010.

[EC 2001] Commission of the European Communities: European Transport Policy for 2010: Time to Decide. White Paper, Brussels, 2001.

[Ehsani 2004] Ehsani, M.: Modern Electric, Hybrid Electric, and Fuel Cell Vehicles, 2004.

[Ellison & McNaught 2000] Ellison, G.C.; McNaught, R.: The Use of Natural Fibres in nonwoven Structures for Applications as Automotive Component Substrates, Research & Development Report, 2000, viewed 24 May 2011, http://www.ienica.net/usefulreports/auto.pdf

[EPS 2008] Heikkinen, A.; Hes, M.; Llanos, J.; Houten, A.; Wegrzynowski, D.: Reduction of Air Resistance for the RUF-Vehicle, 2008.

[EU Commission 2011] European Commission: Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system, Brussels, 2011, viewed 24 May 2011, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0144:FIN:EN:PDF

[Ewing 2011] Ewing, S.J.: Hyundai Blue2 fuel cell concept brings "Intersected Flow" design to Seoul, 2011, viewed 24 May 2011, http://www.autoblog.com/2011/03/31/hyundai-blue2-fuel-cell-concept-brings-intersected-flow-design/#continued

[Ferreira 2011] Ferreira, A.; Antunes, P.; Herskovic, V.: Improving Group Attention: An Experiment with Synchronous Brainstorming, Springer Science+Business Media, 2011.

[Garrett et al. 2001] Garrett, T.K..; Steeds, W.; Newton, N.: The Motor Vehicle, 2001, Reed Educational and Professional Publishing Ltd, Oxford, 2001.

[Gartner n.d.] Gartner: Gartner Hype Cycle, viewed 22 March 2011, http://www.gartner.com/technology/research/methodologies/hype-cycle.jsp

[Geiger 2010] Geiger, T.: Olive seeds and coconut fibre: natural raw materials in our cars, Deutsche Presse Agentur, 2010, viewed 24 April 2011, http://www.monstersandcritics.com/lifestyle/life/features/article_1608506.php/Olive-seeds-and-coconut-fibre-natural-raw-materials-in-our-cars

[German 2008] German, J.: Weight Reduction and Safety Implications, Passenger Vehicle GHG Symposium, 2008, viewed 24 April 2011, http://www.arb.ca.gov/cc/ccms/meetings/042108/4_21_current_techn_4_german.pdf

[Goodyear 2010] Goodyear Innovation: Next Generation Products on Display at Geneva Motor Show, viewed 24 April 2011, http://www.goodyear.com/cfmx/web/corporate/media/news/story.cfm?a_id=126

[Helman 2010] Energy Matt Simmons, Forbes Blog, 2010, viewed 24 April 2011, http://blogs.forbes.com/christopherhelman/2010/08/09/matt-simmons-crazy-uncle-of-the-oilpatch-r-i-p/

[Henricks 2008] Henricks, M.: Do You Really Need a Business Plan? Entrepreneur, 12/2008, Vol. 36, Issue 12, p. 92-95.

[Hodgson n.d.] Hodgson, D.: The Urbanisation of the World, Fairfield University, n.d., viewed 24 April, http://www.faculty.fairfield.edu/faculty/hodgson/Courses/so11/population/Urbanisation.htm

[Hughes 2008] Hughes, Ivy: A simple plan. Entrepreneur, 08/2010, Vol. 38, Issue 8.

[IfM n.d.] Institute for Manufacturing: Morphological charts, University of Cambridge, viewed 20 March 2011, http://www.ifm.eng.cam.ac.uk/dmg/tools/concept/morph.html

[Jensen 2003] Jensen, Palle R.: Drive system for transport system of the dual mode type, Patent no.: US 6,523,480 B1

[Jensen 2008] Jensen, Palle R.: RUF International Investment case, viewed 24 April 2011, http://ruf.dk/rufinvest.pdf

[Jensen 2010] Jensen, Palle R.: RUF capacity, RUF International, 2010, http://www.ruf.dk/rufcapacity.pdf

[Jusoh 2008] Jusoh, M.J.B.: Studies on the properties of woven natural fibres reinforced unsaturated polyester composites, UNIVERSITI SAINS MALAYSIA, 2008, viewed 24 April 2011, http://eprints.usm.my/10367/1/STUDIES_ON_THE_PROPERTIES_OF.pdf

[Katz 2008] Katz, J.: Race Car Aerodynamics. Designing for Speed, Bentley Publishers, 2003.

[Kodjak 2007] Kodjak, D.: Passenger Vehicle Greenhouse Gas und Fuel Economy Standards. A Global Review. 2007. ICCT (International Council on clean Transportation), viewed 24 April 2011, http://ec.europa.eu/clima/events/0005/8_icct_en.pdf

[Koser 2010] Koser, U.: Zukunft der Automobiltechnik, Lecture at the University Erlangen-Nuremberg, 2010.

[KPMG 2011] KMPG International: KPMG's Global Automotive Executive Survey 2011, viewed 24 April 2011, http://www.kpmg.com/Global/en/IssuesAndInsights/ArticlesPublications/Documents/Global-Auto-Executive-Survey-2011.pdf

[Landis 2008] Landis, M.; Jerris, S. I.; Braswell, M.: Better Brainstorming, Journal of Accountancy, 2008.

[Larminie 2004] Larminie, J.: Electric Vehicle Technology Explained, 2004.

[Lesemann et al. 20009] Lesemann, M.; Benmimoun, M.; Lützow, J.; Zlocki, A.; Gies, S.:eVALUE - A Test Programme for Active Safety Systems, Institute für Kraftfahrzeuge, RWTH Aachen University, 2009, viewed 24 April 2011, http://www-nrd.nhtsa.dot.gov/pdf/esv/esv21/09-0137.pdf

[Litchfield 2008] Litchfield, R. C.: Brainstorming reconsidered: A goal-based view, Academy of Management Review, 2008.

[Loten 2011] Loten, A.: 'Startup America' Embraces Crowd-funding, The Wall Street Journal, 2011, viewed 24 April 2011, http://blogs.wsj.com/in-charge/2011/04/22/%E2%80%98startup-america%E2%80%99-embraces-crowd-funding/

[Pheasant & Haslegave 2006] Pheasant, S.; Haslegrave, C.M.: Bodyspace. Anthoropometry, Ergonomics and the Design of Work, Third edition, Taylor & Francis, 2006.

[Powell 2009] Powell, A.: Amory Lovins talks energy solution, Harvard university office for Sustainability, 2009, viewed 24 April 2011, http://www.green.harvard.edu/amory-lovins-talks-energy-solutions

[Santoni 2010] Santoni, C.: The McLaren MP4 - 12C carbon fibre "MonoCell", McLaren Automotive, 2010, viewed 24 April 2011, http://speautomotive.com/SPEA_CD/SPEA2010/pdf/KEY/K4.pdf

[Presting & König 2003] Presting, H.; König, U.: Future nanotechnology developments for automotive applications, Materials Science and Engineering, 2003, viewed 24 April 2011, http://www.sciencedirect.com/science/article/pii/S0928493103002169

[Prentice 2010] Prentice, C.: Cash-strapped entrepreneurs get creative. BBC News, New York, 2010, viewed 24 April 2011, http://www.bbc.co.uk/news/10100885

[Reimpell et al. 2001] Reimpell, J.; Stoll, H.; Betzler, J.W.: The Automotive Chassis: Engineering Principles, Second edition, Butterworth-Heinemann, 2001.

[Renault 2011] Renault Twizy, viewed 25 April 2011, http://www.renault.com/en/vehicules/renault/pages/twizy.aspx

[Machin 2010] Machin, W.: Can You Drive Without a Side Mirror? 2010, eHow, viewed 24 April 2011, http://www.ehow.com/facts_6723742_can-drive-side-mirror_.html

[Mason 2011] Mason, R: Shell chief Peter Voser warns oil demand could outstrip supply. March 2011, The Telegraph, http://www.telegraph.co.uk/finance/oilprices/8362579/Shell-chief-Peter-Voser-warns-oil-demand-could-outstrip-supply.html

[Melfi 2011] Melfi, T.: Audi Dialoge - Das Audi-Technologiemagazin, AUDI AG, 2011, https://www.audi-mediaservices.com/publish/ms/content/de/public/broschueren/2011/04/11/Das_Technologiemagazin/audi_dialoge_110504.-bin.acq/qual-DownloadFileList.Single.DownloadFile.0001.File/Audi_Dialoge_110504.pdf

[Mitchell 2010] Mitchell, W.J.; Borroni-Bird, C.E.; Burns, L. D.: Reinventing the Automobile: Personal Urban Mobility for the 21st Century, 2010.

[OmniVision 2009] OmniVision Technologies: Automotive Backgrounder, 2009, viewed 24 April 2011, www.ovt.com/news/presskit.php?ID=15

[Paddock 2010] Paddock, B.: NY Auto Show gets futuristic: Infiniti Essence uses cameras instead of rear-and side-view mirrors, Daily News, viewed 24 April 2011, http://articles.nydailynews.com/2010-04-05/news/27060824_1_cameras-blind-spot-ny-auto-show

[RM 2011] Revenue Management: The ins and outs of penetration pricing, Applied Revenue Management, 2011, viewed 24 April 2011, http://revenue-management-2010.blogspot.com/2011/02/ins-and-outs-of-penetration-pricing.html

[Ryan & Lidderdale 2009] Bob Ryan and Tancred Lidderdale: Energy Price Volatility and Forecast Uncertainty. Energy Information Administration, 2009 http://www.eia.doe.gov/emeu/steo/pub/special/pdf/2009_sp_05.pdf

[Schewel et al. n.d.] Schewel, L.; Simpson, M.; Chourdia, P.: Vehicle Safety survey Quantifying Perceptions of Weight and Materials., viewed 24 April 2011, http://move.rmi.org/files/lightweight%20survey/Safety_SurveyGraphs_081224_v9_MS.pdf

[Selviah et al. 2007] Selviah, D.R.; Wang, K.; Richards, M.: The AutoEye Mark 1 Vehicle Rear View Camera Vision system, Department of Electronic and Electrical Engineering, University college London, 2007, viewed 24 April 2011, http://eprints.ucl.ac.uk/4313/1/4313.pdf

[Smith 2010] Smith, C.: Cars of the future could be powered by their bodywork thanks to new battery technology, Imperial College London, 2010, viewed 24 April 2011, http://www3.imperial.ac.uk/newsandeventspggrp/imperialcollege/newssummary/news_5-2-2010-10-26-39

[Stauber 2009] Stauber, R.: Werkstoffe im Automobilbau, BMW AG, Lecture at the University Erlangen-Nuremberg, 2009.

[Stier 2008] Stier, K.: The 'Peak Oil' Theory: Will Oil Reserves Run Dry?, CNBC, 2008, viewed 24 April 2011, http://www.cnbc.com/id/23728987

[Strauss 2011] Strauss, L.C.: Whatever Happens in Egypt, Oil Will Hit $300 by 2020, Barron's, 2011, http://online.barrons.com/article/SB50001424052970204098404576130370708044708.html?mod=BOL_hpp_popview#articleTabs_panel_article%3D2

[United Nations 2002] United Nations: How to prepare a good Business Plan, Conference on Trade and Development, 2002

[United Nations 2004] World Urbanisation Prospects: The 2003 Revision. Department of Economic and Social Affairs, United Nations, 2004. http://www.un.org/esa/population/publications/wup2003/WUP2003Report.pdf

[Vesco 2011] Vesco, M.: Composites for Mass Production, 2nd Innovative International Composites Summit, Paris, 2011, viewed 24 April 20011, http://www.jeccomposites.com/sites/default/files/content/files/Programme%20IICS%20Paris%202011_110318.pdf

[Wakeham 2009] Wakeham, K.J.: Introduction To Chassis Desgin, 2009, viewed April 2011, http://www.keithwakeham.com/Files/ChassisDesign.pdf